

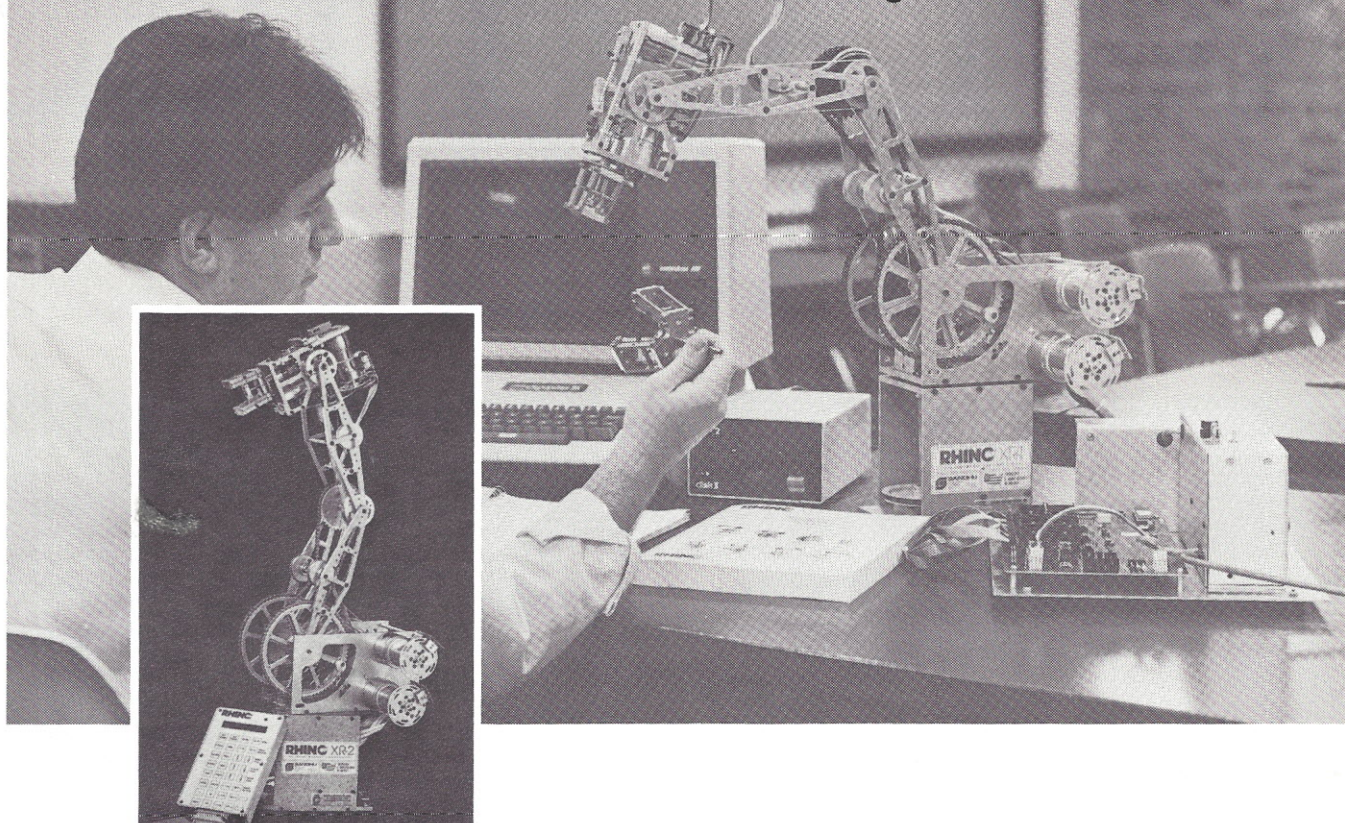
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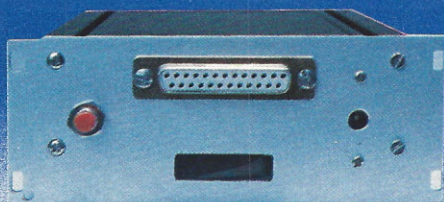
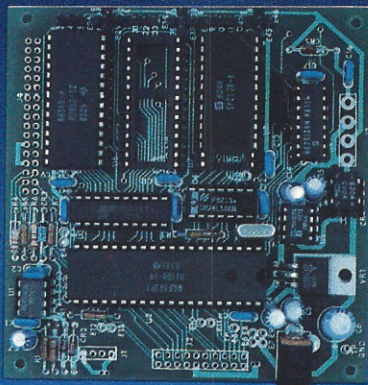


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Calendar

SEPTEMBER

September 19-21. 9th Annual Advanced Control Conference. Fowler Hall, Purdue University, West Lafayette, IN. Contact: Henry Morris, Conference Coordinator, Control Engineering, 1301 South Grove Avenue, PO Box 1030, Barrington, IL 60010. (312) 381-1840.

This year's conference is entitled "Learning Systems and Pattern Recognition in Industrial Control." Conference subjects include: speech recognition, intelligent vision systems, robotics, and artificial intelligence.

September 19-30. 2nd Annual Computer Science at UCLA. UCLA Extension, Los Angeles, CA. Contact: UCLA Computer Science Department, 3732 Boelter Hall, Los Angeles, CA 90024. (213) 825-2929.

Classes are abridged versions of UCLA Computer Science Department regular daytime courses. Plenary sessions pro-

vide a special opportunity to hear outstanding leaders in the computer field.

September 20-22. ASSEMBLY Technology Expo. O'Hare Expo Center, Rosemont, IL. Contact: Steve Bernstein, Professional Exposition Management Company, Inc., Suite 205, 2400 East Devon Avenue, Des Plaines, IL 60018. (800) 621-2134, (312) 299-3131.

ASSEMBLY Technology Expo is the nation's marketplace for ideas, equipment, materials, systems and methods of aid to the manufacturing manager/engineer to help increase productivity, performance and quality, save time and labor, control costs and contribute to profitability.

September 27-28. IEEE Computer Society Twelfth Workshop on Applied Imagery Pattern Recognition. University of Maryland University College, Center of Adult Education, College Park, MD 20742. Contact: IEEE Com-

puter Society Press, PO Box 639, Silver Spring, MD 20901.

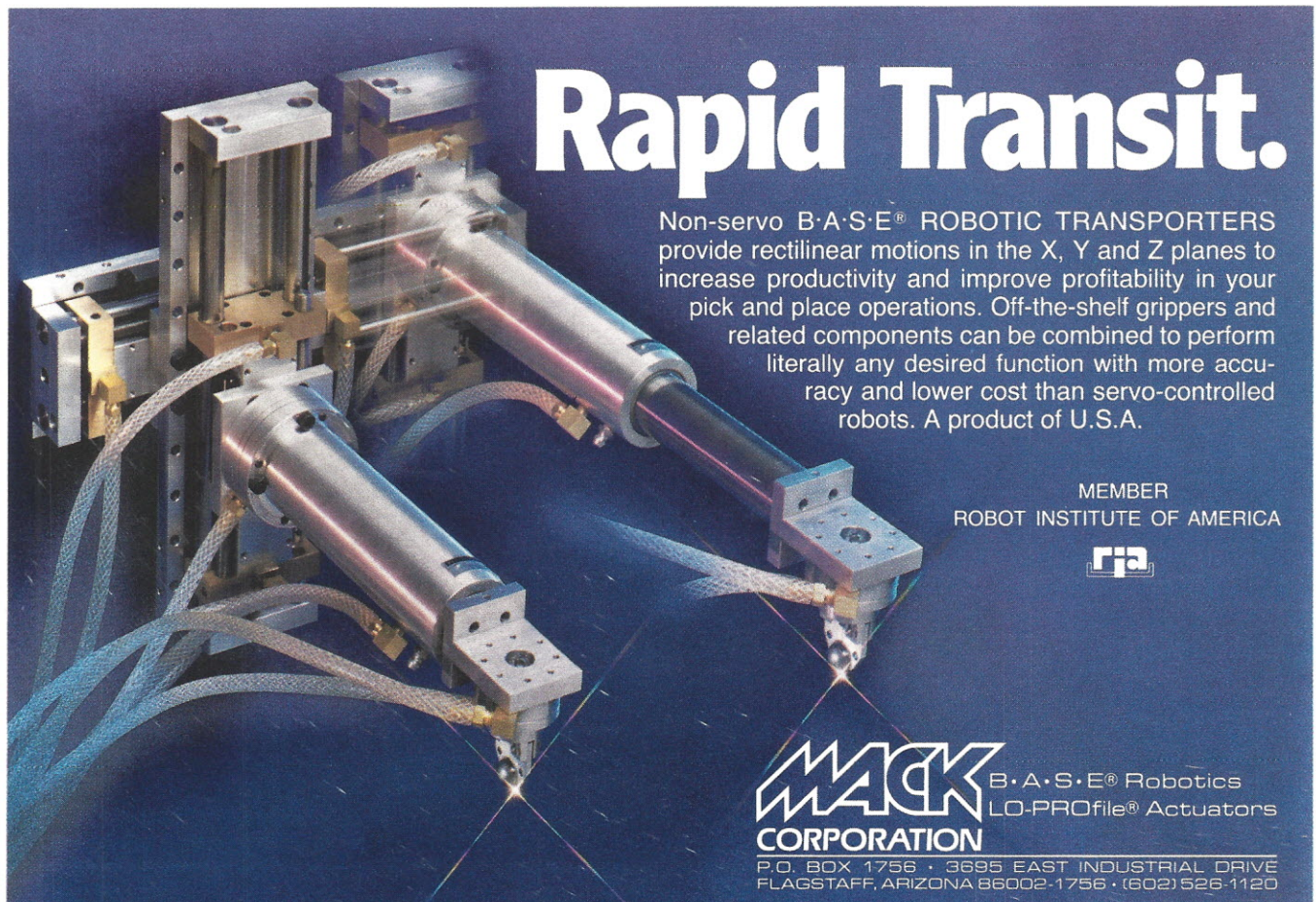
The theme of this year's conference is the integration of hardware and software components into working machine vision systems. The conference includes a concurrent classified session conducted under the auspices of the Night Vision and Electro-Optics Laboratory. Topics to be discussed include: image processing architectures; image processing algorithms; robot vision; space systems; cartographic systems; biomedical technology.

OCTOBER

October 2-5. Robotech 83. Curtis Hixon Convention Hall, Tampa, FL. Contact: Gene Bignami, Mitch Hall Associates, Robotech 83, PO Box 860, Westwood, MA 02090. (603) 329-8334.

Titled "The International Conference and Exposition for the Application of Automated Manufacturing Technology,"

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THE JOURNAL OF INTELLIGENT MACHINES

ROBOTICS AGE™

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About the Cover: Walking machines are just beginning to appear on the design horizons of experimental robotics. One fascinating example, the Odex I machine, is shown on this month's cover. This conceptual prototype, designed by Odetics, Inc., is reminiscent of some of the critters seen briefly at the start of the latest Star Wars epic, *Return of the Jedi*.

The cover photo, supplied by Odetics, Inc., shows the Odex I beginning a motion sequence of walking up into a small pickup truck. The Odex I can also reverse the action and walk down out of the truck. If it can handle trucks, stairs can't be far behind.

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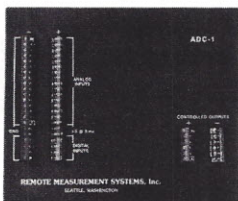
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Editorial

Educational Tools

BY RAYMOND GA COTÉ

Education is one of this year's major concerns. Every week, a half-dozen people call us to ask, "Which schools provide robot-related degrees?" or "Which universities are best known for their work in robotics and artificial intelligence?" Although we are unable to recommend schools to these people, we can say that the number of schools is growing rapidly. Many trade schools have already started robot repair and technician courses aimed at the people who will one day install and repair robotic machines. The Robotics International trade organization is compiling a list of universities, colleges, and trade schools that offer courses in robotics engineering and related fields.

A second major request comes from the educational institutions themselves. Instructors constantly ask, "Where can I find information about laboratory systems and instructional kits for servomechanisms, pneumatics, and so on?"

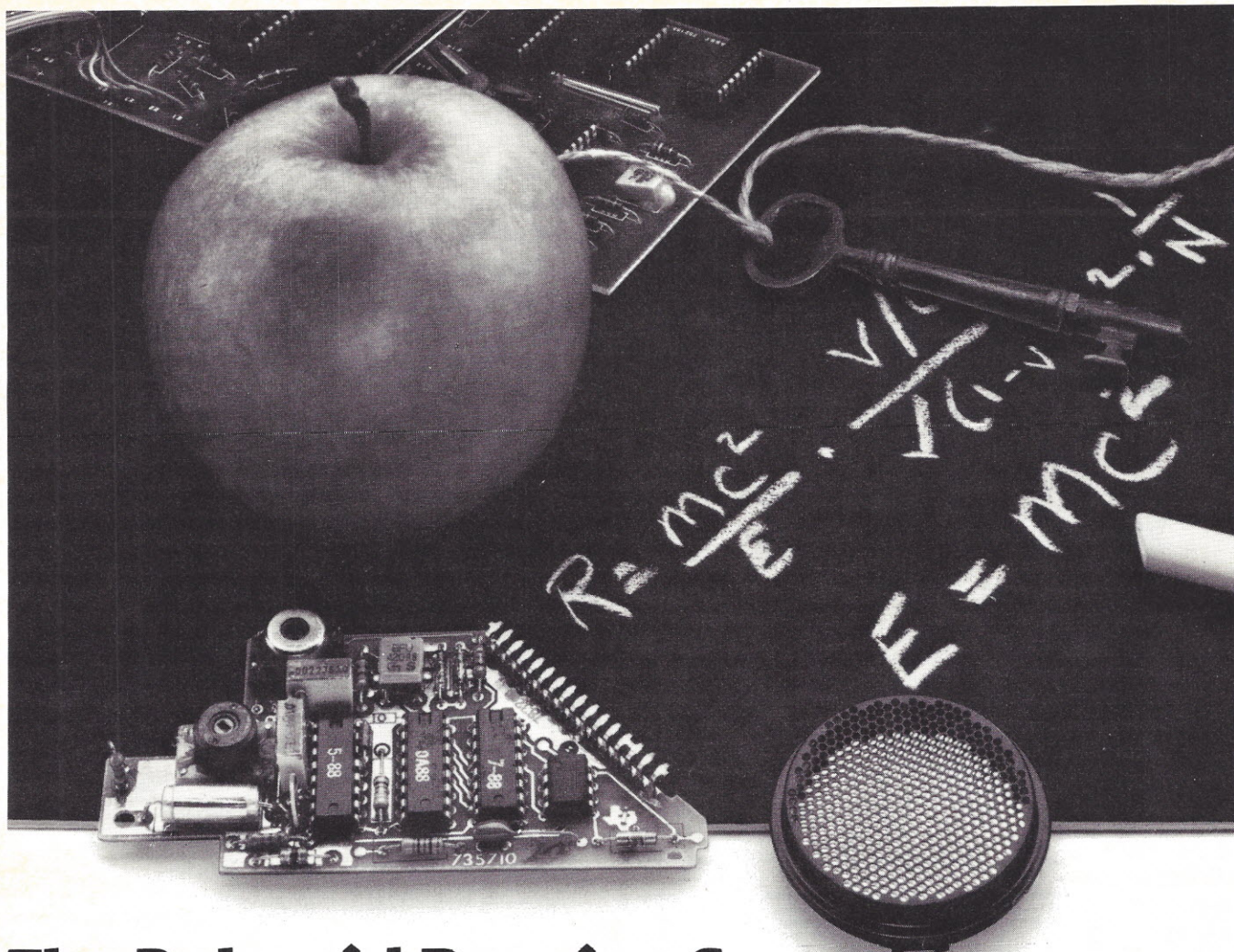
Products such as the Microbot Minimover or the Rhino arms answer one aspect of this question. These arms provide a robotic device that can be connected to common computers and emulate the motions of multi-thousand dollar robots. Complete systems such as the Heath Hero 1 provide a comprehensive experimental platform for real-time programming experiments and hardware integration. Information and hands-on experience, however, are also required at a lower level.

The May/June *Robotics Age* published a letter from Joe Day requesting information on lab kits for basic servo control experiments. Several manufacturers and schools responded with descriptions of products that are useful in laboratory and educational settings.

Feedback, Inc. has manufactured instructional servos for over 25 years. Included in their extensive catalog are a low-cost electro-mechanical servo demonstrator and a kit that allows experimentation with both AC and DC servomotors. Feedback also provides experimental equipment to control servomotor position, speed, direction, and so on. All pneumatic and electrohydraulic laboratory systems are also available.

Feedback offers a low-cost, 3-axis, computer-numerically-controlled drill that can be connected, through the appropriate interface, to PET, Apple, TRS-80, and AIM-65 computers. One of Feedback's most interesting products is the Armdraulic robot arm. To my knowledge, it is the only small, experimental, hydraulic arm.

Richard LaRiviere of the Smith Vocational-Agricultural High School writes that the Hampden Engineering Corp. also has several kits that can be used for servo experiments. I have no further information on these kits.



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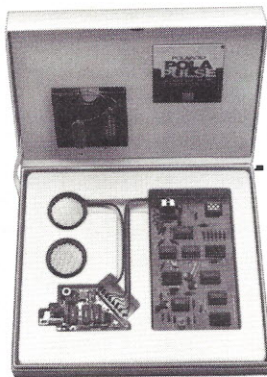
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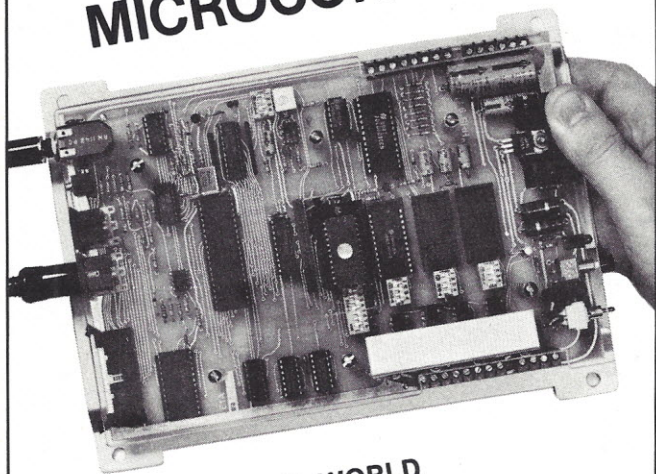
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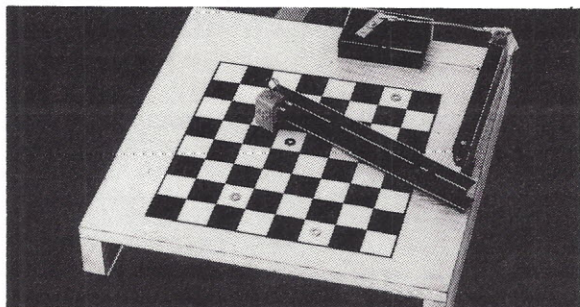
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Editorial

Glenn R. Farmer, Placement Director at the Electronics Institute in Kansas City, Missouri, wrote to say that the institute offers a very thorough electro-mechanical course including 360 hours of microprocessor/hydraulics-pneumatics technology. He informed me of the Electro-Mechanical Training System from Technical Systems, Inc. The trainer and accompanying manuals are designed to cover a two-year course. Course topics include: basic electricity and mathematics, semiconductor fundamentals, AC circuits, operational amplifiers, communications systems, digital and analog electronics, 6502 and 8080 microprocessor architectures, pumps and compressors, valves and actuators, and fluid control systems.

Amptronics also has several training systems. Their design for the pneumatically-controlled BRAT (Basic Robotic Automated Trainer) laboratory system resulted from their difficulty in finding qualified engineers. Thus, the BRAT is designed to use industry-standard parts. The devices with which students experiment in the lab are the same components found in real-world factories.

Empire Electrical Company represents a product line from Electro-Craft that includes the MOTOMATIC Control System Laboratory. This system is designed for a one-year course in electro-mechanical control systems. A sample of the experiments that can be performed include: amplifiers for control systems, transient response, velocity, position, and adaptive control, pneumatic loading, weight measurement, bang-bang control, effects of backlash, and linear state feedback.

Automat construction kits may be the ultimate answer for people interested in industrial-quality modeling kits. Constructed in Germany and marketed in the United States by Stock Model Parts, the Automat line consists of five different breadboarding kits which range in size from a basic 2600-part kit to a 4100-part kit containing special-purpose gear and cam drives, linkages, and universal joints. These kits provide the materials for constructing complex mechanical models without special tools.

These are the only systems about which I have any current information. I would like to hear from people who know about training or laboratory systems I have not mentioned. Tutorial articles describing the design and use of servomotors as well as hydraulic and pneumatic systems are always welcome.

Editorial

Olympics of the Mind. In addition to having the right technical training, solving new and unusual engineering problems also requires a certain way of thinking. The "Olympics of the Mind" competition is designed to foster creative problem solving among high school and grammar school students.

A telephone call to the organizers, Creative Competitions, Inc., provided the following information. Each year, the Olympics of the Mind competition is presented as a set of long-term projects from which various teams select interesting problems. The competing students are divided into three divisions: division I, grades K-5; division II, grades 6-8; and division III, grades 9-12. Winning teams are chosen from each division for each problem.

The problem areas cover a variety of topics. Last year's problems ranged from constructing a spring-powered car (the classic Leonardo da Vinci Spring Car) through rewriting scenes from Homer's classic epics (Humor From Homer).

The object of one problem titled the "Miner's Helper" was to design and construct a device capable of exploring fanciful gold or silver mines. The Miner's Helper would roam an area and retrieve valuable "minerals." Ideally, the device would distinguish between "minerals" (two white ping pong balls and one orange tennis ball) and worthless "rocks" (three colored ping pong balls and three yellow tennis balls). One restricting factor was a \$35 price ceiling.

All three winning teams approached the problem differently. The division I winners, from the



Photo 1. The winning division II team from left to right: Peg Moser, Roberta Krumholz, and Pam Gray (coaches), David Simon, Robert Shapiro, Roy Morton, Brad Krumholz, David Kadesh, and Blair Miicke.

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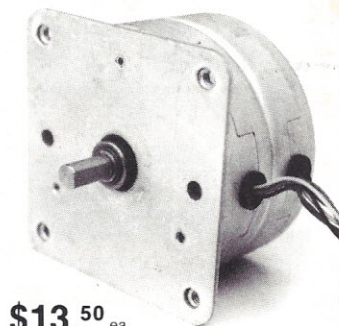
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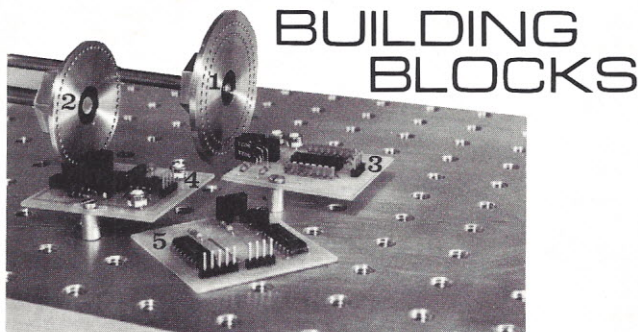


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Editorial

Chesapeake Demo School in Virginia, designed a very simple device. They attached a long rubber hose to a box and wound a sturdy rubber band around the end of the hose. Contestants used long wooden sticks to steer the Miner's Helper to the minerals (balls). Another long stick forced the rubber hose over the ball. The ball squeezed through the constriction caused by the rubber band and then held in place by the band. Lifting the hose caused the ball to slip down the hose to the waiting box.

The division II winners, from Mountainside School District in New Jersey (photo 1), designed a box attached to a 12-foot pole. After they placed the box over the minerals, they used a graduated ramp to pull the minerals up into a collection area. They chose a simple mechanical device over an electrical device to avoid unforeseen potential problem areas.

The division III winners produced the most complicated device. The team from Warrensville Heights, Ohio used a drive control mechanism similar to that found in many remote toy cars. The control box allows the two wheels to be turned independently for steering. The shovel mechanism used two smaller DC motors with reduction gears to reduce speed and increase pulling power. One motor raised and lowered the shovel while the other opened and closed a curved scoop to trap the minerals (balls).

After using the remote control to move the Miner's Helper to a target ball, the shovel was lowered and closed to entrap the ball. Raising the shovel caused the ball to roll out of a top opening and into the mineral sample box. The students constructed this device from scrap aluminum and tin, some Erector

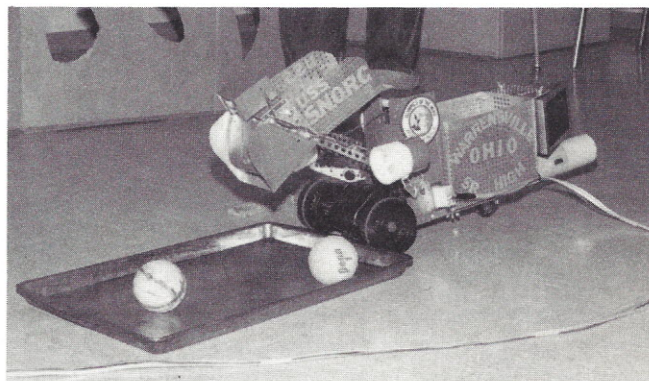
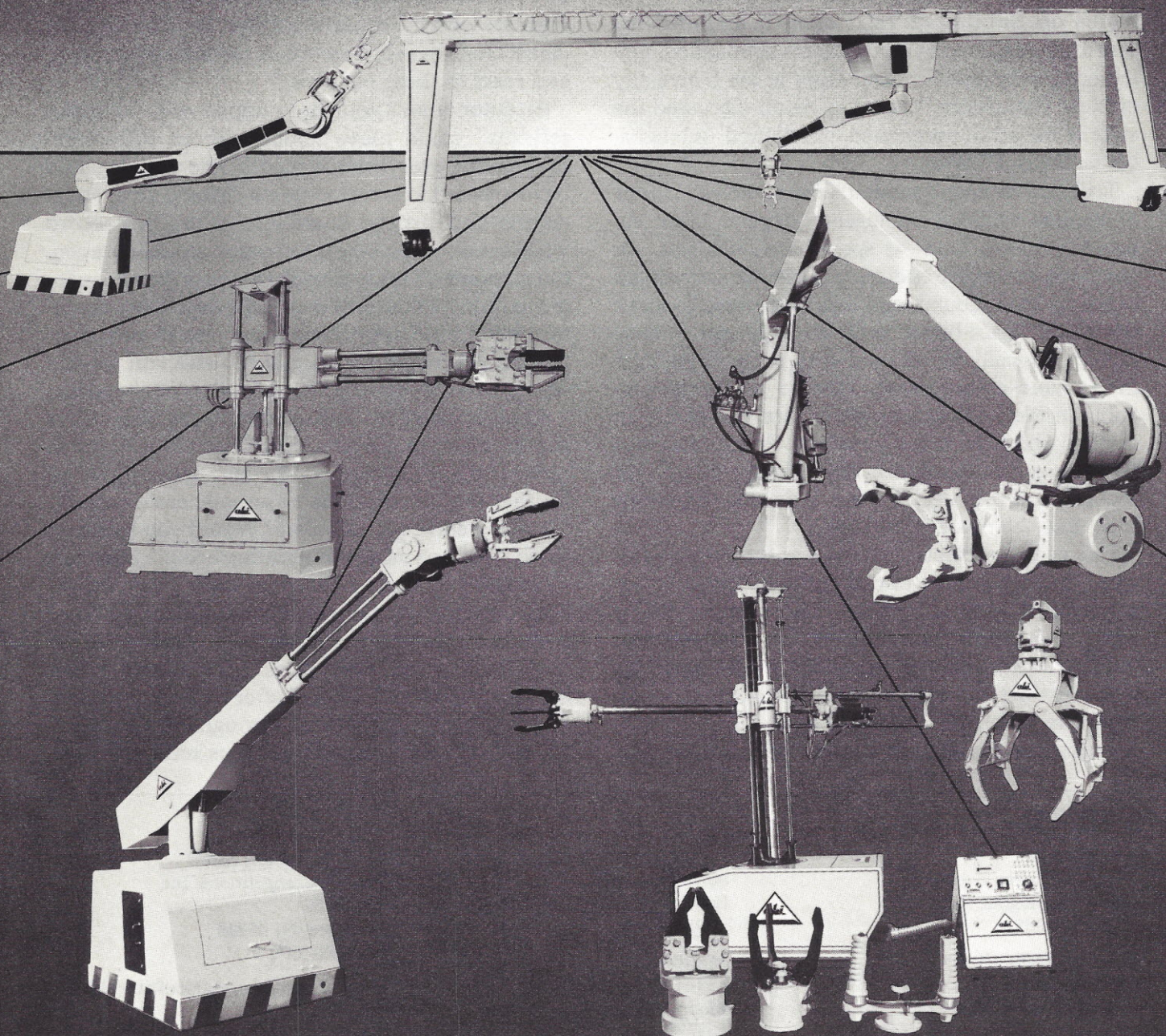


Photo 2. The division III team envisioned an underwater Miner's Helper. The SNORC (Submersible Nautical Ore Recovery Company) device was designed by David Benthimer, Kevin Harris, David Tyus, Brian Bowling, Kevin Sedensky, and Christopher Wright. Coaching was provided by Dennis Ross and Dan English.

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Editorial

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Notes on Submersibles. I recently attended the Third International Symposium on Unmanned, Untethered, Submersible Technology at the University of New Hampshire. The symposium discussed the state of the art in unmanned, untethered, submersible vehicles (UUSVs).

Truly autonomous submersibles stretch the limits of applied artificial intelligence beyond those encountered with land- or space-based vehicles. An autonomous vehicle operating in a land environment can stop, look around, and take some time to make decisions. Space-borne vehicles, although moving rapidly, typically spend most of their operating lives in a stable environment, relative to themselves. Submersible vehicles, however, are constantly in motion. Since the water about the vehicle is always flowing, a submersible cannot simply stop, look around, and then decide what to do next. Decisions must truly be made in real time.

One of the subjects discussed at the symposium was the need for "artificial reflexes" versus "artificial intelligence." I think you will agree that a typical fish is not very intelligent. Yet, a healthy fish manages to keep from running into obstructions. The fish's instinct and reflexes note the proximity of an object and steer the fish away from it.

Some biological theories propose that the fish may

not even be "aware" of the object it is avoiding. This is analogous to the human reflex of pulling a hand away from a hot stove before the sensation of "hot" registers with the conscious mind. The fish's senses detect changes in light or water motion and pressure and react to these changes.

An autonomous vehicle equipped with "artificial reflexes" could move about without fully comprehending everything it senses. The vehicle could be instructed to travel within a defined area, avoid objects, and carry on-board sensors to either record what is seen or send the information directly to a central computer. This approach removes the necessity of analyzing volumes of confusing data. Only the information vital to avoid running into objects is required. Although not necessarily efficient, such a device could operate without human intervention.

Another problem facing untethered vehicles is communication. An air- or space-borne vehicle can communicate through radio and laser linkages. Neither method works in an aquatic environment.

How to solve this problem? Would you believe a sonic, 4800 bps modem operating through 5000 feet of water? Just such a "sonic modem" has already been used to transmit medium resolution, digitized pictures through open waters. I'll leave a full explanation of the difficulties encountered when deciphering an audio signal after it has bounced off floating objects and passed through varying water temperatures to some adventurous audio engineer.

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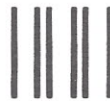
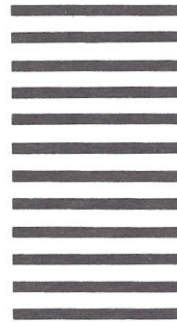
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IBM EDUCATIONAL GRANTS. IBM has awarded complete CAD/CAM development systems to 20 universities. The awards are part of a \$50 million corporate program designed to encourage education for excellence in manufacturing systems at American engineering schools. The 20 recipients were chosen from among 115 university applications. Each of the awarded CAD/CAM systems consists of an IBM 4341 Group II data processor with 16 Mbytes of main memory, 6.6 billion character direct access storage devices, graphic, color, and remote displays.

BILINGUAL RECOGNITION. Scott Instruments Corporation has formed Scott Instruments Canada, Inc. in association with Convergent Technologies, Inc. of Canada. The company plans to adapt the Scott Voice-Based Learning System for the English-French speaking Canadian market. Dr. Brian Scott, company president, views this move as the first step towards exploiting Scott's voice recognition products in worldwide markets.

AVATAR REVISITED. Remember Avatar? (*Robotics Age* January/February 1982, page 20). This experimental robot's image has since appeared in publications

from coast to coast. This national interest has prompted Avatar's creator, Chuck Balmer, to establish his own company. Chuck intends to develop and manufacture a personal robot. The time of the truly useful personal robot is fast approaching, and Chuck intends to be out in front with his own product.

HEROIC EFFORTS. Take a major electronics company, assign a robot design project to the R&D team, fund liberally, and allow several years of intensive work. The result is a product such as the Heath Hero 1 robot. By itself, the Hero 1 is an excellent device for teaching the fundamentals of robot control. It provides a training ground for real-time programming mixed with a wide assortment of sensors. No matter what the product, however, people always want improvements.

Several companies already have appeared with Hero 1 enhancements. Perbotics, Inc. and Interface Technology have introduced products such as additional programmable memory, RS-232C ports, CP/M-based development systems, and additional processors and languages.

Speaking of the Hero 1, watch for the Sams book *Hero 1 Advanced Programming and Interfacing*.

NASA/NBS REPORTS. NASA and the National Bureau of Standards have released a series of reports on robotics and artificial intelligence subjects. The series summarizes techniques, available systems, participating companies, future trends, and technological opportunities.

So far the following areas have been addressed: robotics—increased productivity, hazardous environment operations, human surrogates; expert systems—human assistance in medical diagnosis, planning, design, signal interpretation, and instruction; computer vision—robot guidance, industrial automation, inspection, image interpretation, and aids for the visually handicapped; natural language processing—interactions with computers for data base management, question answering systems, natural language translation, and text or speech understanding and generation. For more information, contact the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. (703) 487-4600.

ROBOTICS SOFTWARE PROJECT. CAM-I, a non-profit membership organization engaged in the research and develop-

Continued on page 56

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In addition to the 12 arm axes, 'MARVIN' has:

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Drive Wheels- Each drive wheel is an individual servo to enable directional control. His maximum rate of forward speed is 50 inches per second and he has enough power to climb a 10% incline.

ODEX I: THE FIRST FUNCTIONOID

Marvin Russell, Jr.
Odetics, Inc.
1380 S. Anaheim Boulevard
Anaheim, California 92805

Functionoid is a term given to a machine for a new era in robotics, a word coined by an American company pioneering this era.

The first functionoid, unveiled in Los Angeles last March by its developers, Odetics, Inc., of Anaheim, California, is a capabilities model we dubbed ODEX I. It walks on six articulators, or legs, and weighs 370 pounds.

The machine demonstrates a variety of attributes unique to mobile, nonfactory robotics, including unprecedented strength-to-weight ratios and agility. We at Odetics adopted the word "functionoid" to differentiate unmanned vehicle systems (UVS) like ODEX I from the single-function, fixed-platform robots used to automate assembly lines.

Odetics intended the first functionoid to be part of a dawning era in the robotics industry in which a multifunctional unit could literally walk away from the factory floor and perform virtually anywhere.

Later incarnations of the functionoid will perform a number of useful tasks in a wide range of applications, generally in environments dangerous for humans or inaccessible to conventional wheeled or tracked vehicles.

The Los Angeles demonstration, held less than 18 months after development of ODEX I officially

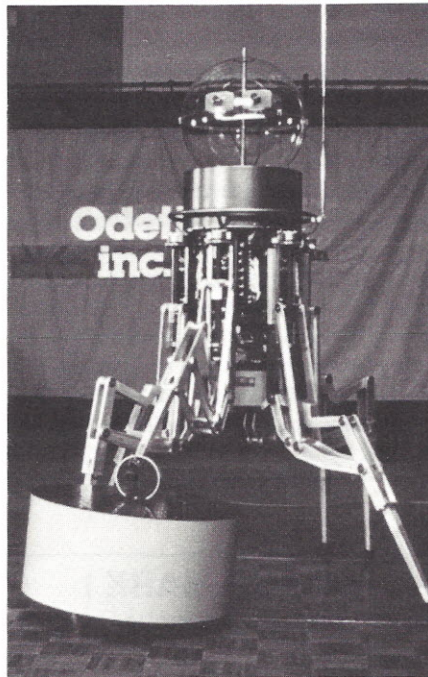


Photo 1. ODEX I executes a feat of agility and strength during the first functionoid's unveiling in Los Angeles last March. In this portion of the demonstration, the unit uses one of its articulators to adjust a swivel ring on top of a pedestal, puts the crutch tip through the ring, then lifts the pedestal. Each articulator can lift as much as 400 pounds.

began, caught many analysts and researchers by surprise, since Odetics is a new entry to the robotics industry. Founded in 1969, Odetics manufactures high-quality audio, digital, and video recording equip-

ment for electronic information processing. The firm's Spaceborne Division has captured more than 70 percent of the world market for digital magnetic tape recorders for use in space vehicles.

Unlike most manufactured products, the functionoid project was not "customer driven;" ODEX I was built without specific applications or customer requirements. The project was the result of a company goal to identify and penetrate a large market to protect the company's long-term growth and competitiveness.

Odetics was the "customer" for the first functionoid and, as such, identified six highly desirable capabilities as ODEX I's design objectives. These included mobility/walking, profile changing, agility/maneuverability, strength, stability, and self-contained power.

A machine possessing these capabilities would serve as the base technology for future functionoids built to perform specialized tasks. This technology would lend itself to such tasks as mining and undersea exploration.

According to a report by SRI International, a Menlo Park, California market research organization, the mining industry needs a machine that includes ODEX I's capabilities in the areas of land and seafloor exploration, fire inspection, hauling, continuous coal mining, and roof-

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■ RTROL: ROBOT CONTROL LANGUAGE

A language (compatible with "Teach-in" programming) which allows program decisions based on any of the input conditions.

RTROL programs can be easily created, displayed and edited with a built-in keyboard, alphanumeric display and printer.

■ DURABILITY:

The RC-101 is constructed to withstand practical industrial use.

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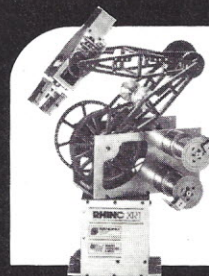
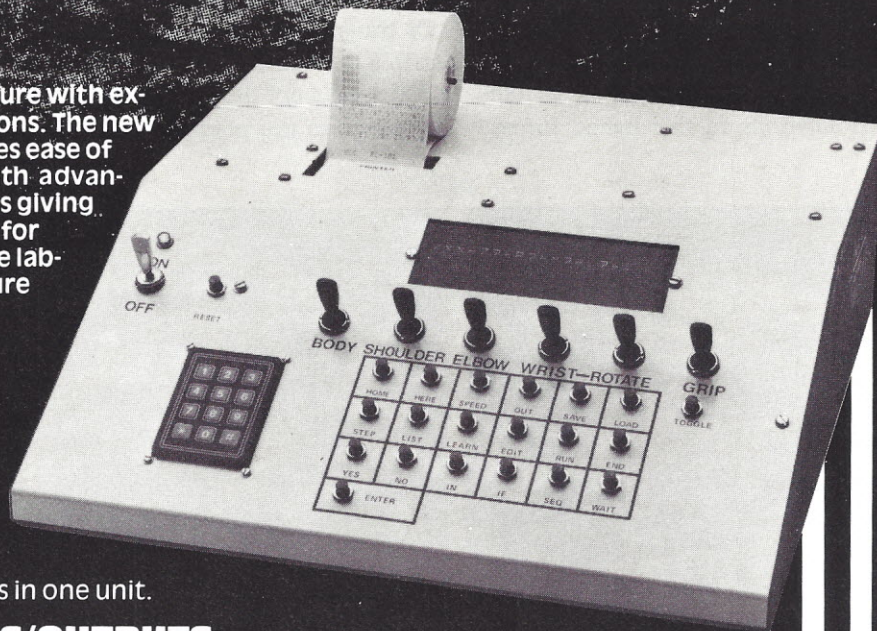
ROBOTS: The RC-101 is currently offered with software for driving Mitsubishi's RM-101 "Movemaster" micro-robot and Sandhu Machine Designs' XR-1 "Rhino". Software for other robots is forthcoming.

■ CASSETTE PROGRAM STORAGE:

This built-in feature allows control programs to be saved or loaded with a cassette storage interface.

■ SOFTWARE:

An **RTROL** language subset for the RM-101 or XR-1 is available for use on the Apple II+ or Franklin Ace.



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bolting.

The nuclear power industry is another promising commercial market. SRI International reports potential applications for functionoids in nuclear power production in the general areas of plant surveillance and inspection, reactor maintenance, decontamination, accident recovery/emergency response, refurbishing/decommissioning, and waste storage.

A functionoid has a number of likely applications in the armed forces.

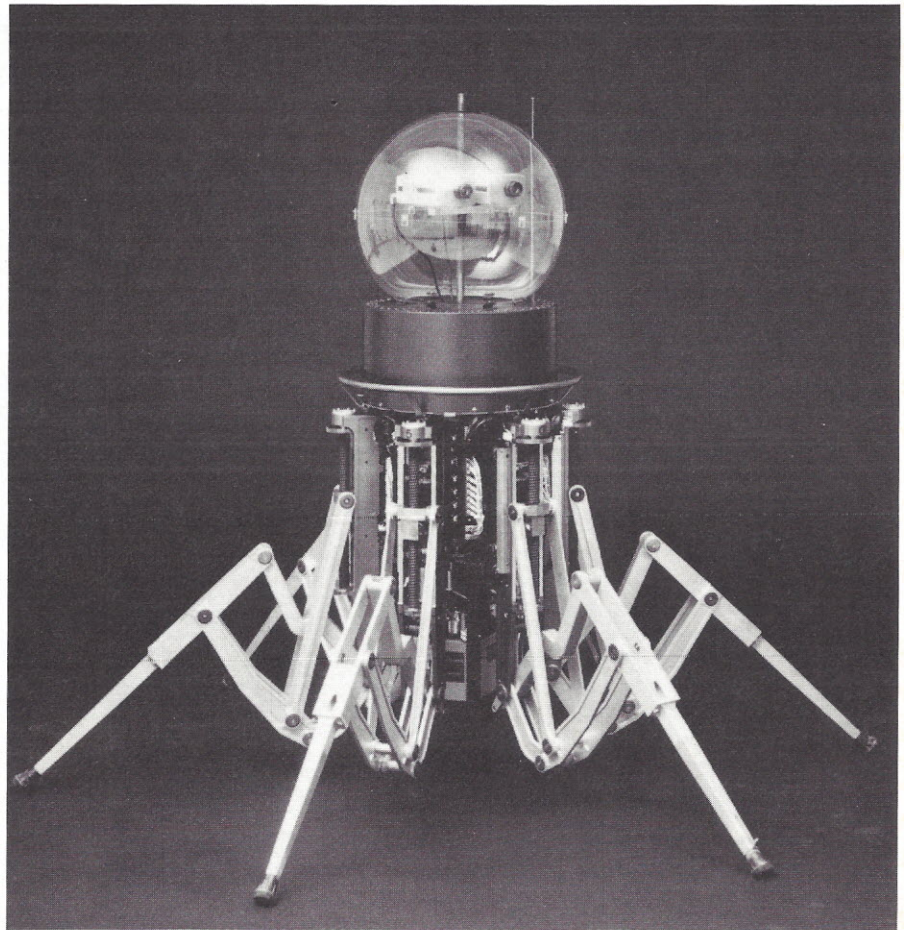
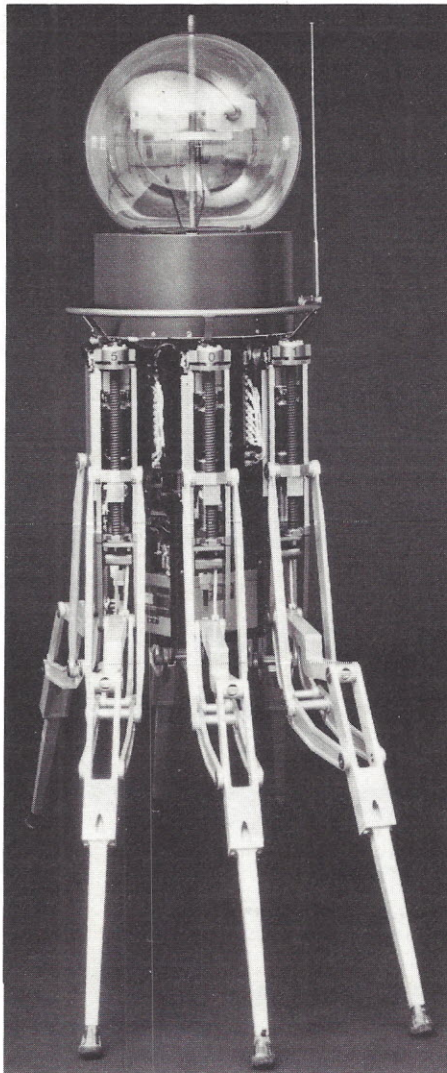
include agriculture, security, forestry, construction, utilities, and medicine.

Maneuverability. The first and most difficult design objective to achieve was the mobility/walking capability. The advantages of a walking machine become quite clear, since wheeled or tracked vehicles can traverse only about half of the earth's land surface.

Odetics is not the first organization to recognize the potential of a walk-

Today, Ohio State University in Columbus and Carnegie-Mellon University in Pittsburgh are the two leading American educational institutions in the research of mobile robotics. The USSR's Moscow State University and a \$140 million cooperative effort between Japanese government and business represent the most extensive overseas development efforts.

Odetics' functionoid's walking attribute is characterized by a tripod



Photos 2a, b. ODEX I can assume several different profiles to adapt to particular applications. In the narrow profile, ODEX I can walk through doorways, hallways, and other narrow openings, with a width of only 21 inches. The squat profile puts the distance between ODEX I's articulators at 72 inches. With the payload area only 36 inches off the ground, ODEX I can continue to walk. This profile also enables ODEX I to assume other profiles very quickly.

The first of these appears to be sentry duty. This is a natural for a machine, since human sentries quickly grow fatigued with this boring work, and it's very costly for the Department of Defense. Other industries to which a functionoid may one day be applied

ing machine. Patents for various types of walking devices date back more than 100 years. General Electric Corporation's four-legged "walking-truck" built for the U.S. Army in the late 1960s is one of the landmark achievements in this field.

gait. The system raises three articulators to advance. These articulators continuously alternate with three other articulators momentarily on the ground supporting the machine.

The three advancing articulators are called "translators," and the

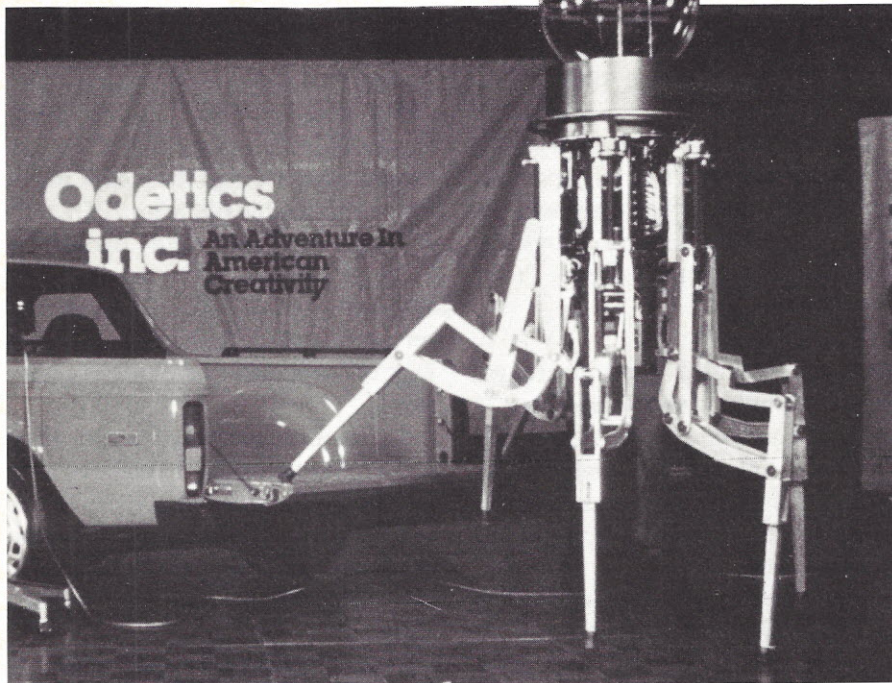


Photo 3. ODEX I begins its demonstration of its climbing capability by stepping onto the tailgate portion of a pickup truck. The functionoid will eventually climb completely into the truck and still be compact enough to allow the tailgate to be closed.

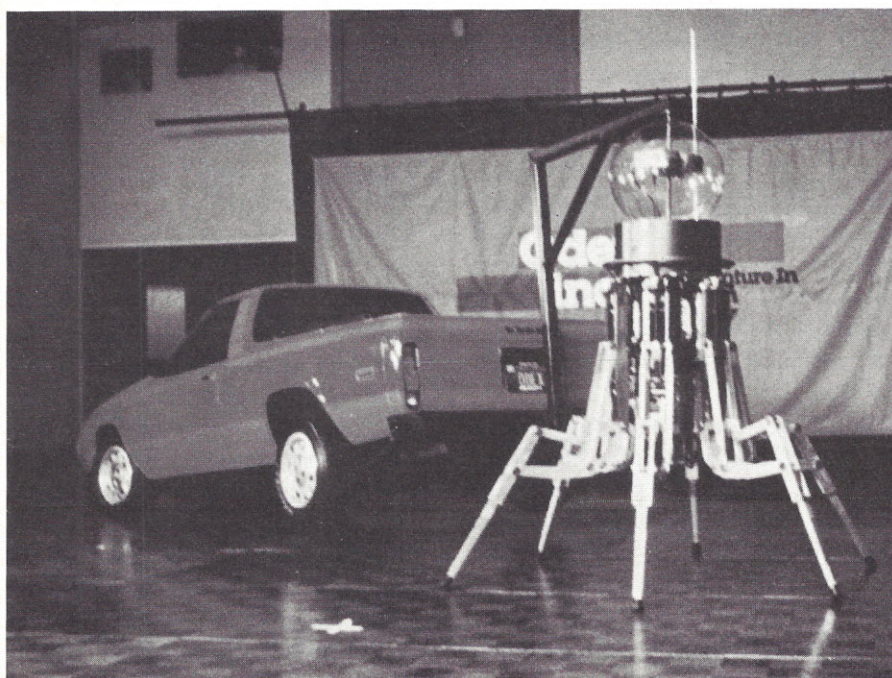


Photo 4. ODEX I walks in the normal profile while lifting the back end of a 2200-pound truck rigged with a special lifting bracket. The first functionoid can lift nearly 900 pounds at normal walking speed, or 2.3 times its own weight.

three load-carrying articulators are called "stokers." The tripod gait was chosen for stability and speed. ODEX I can travel at what, for a person, would be a brisk walk.

Obviously, the more stokers per gait, the greater the functionoid's

payload capacity. We consider the capacity with three stokers to be the acceptable minimum. To develop the walking algorithms, we supported the ODEX I's primary structure from a ceiling beam so that none of the articulators reached the floor.

We also used computer color graphics for this same purpose. Color graphics can indicate quickly whether translators and stokers are in sync. It was an excellent software debugging tool.

In addition to its pure walking ability, the functionoid can assume several different profiles, including what we call tucked, tall, squat, normal, low, and narrow profiles, to adapt to particular applications.

In the tucked profile, with the articulators folded against the primary structure, ODEX I is positioned for minimum exposure. It stands only 48 inches tall, with a total width of 27 inches.

The tall profile raises the payload area to 78 inches, enabling ODEX I to peer over obstacles. The articulators reach maximum extension in this profile at 65 inches.

Though the squat profile puts the distance between articulators at 72 inches, ODEX I can still walk in this position. With the payload area only 36 inches off the ground, this profile has the added advantage of being able to assume other profiles quickly.

The normal profile provides maximum freedom of articulators and maximum speed. With 105 inches between articulators in the low profile, ODEX I's center of gravity is at its lowest point and presents the most stable position. In the narrow profile, ODEX I can walk through doorways, hallways, and other narrow openings with a width of only 21 inches.

We felt that agility/maneuverability and (very importantly) strength were the milestones within our six design objectives that could make the greatest impact in the technology of robotics. We wanted the functionoid to be able to traverse rough terrain and take high steps. Indeed, ODEX I is capable of climbing steps 33 inches high.

To achieve this, we placed on board 18 motors, three associated with each articulator. The largest of the three dictates vertical movement. The other two are identical and control extension and swing.

A dramatic example of this climbing ability was offered during our in-

troductory demonstration when ODEX I climbed into and out of the back of a pickup truck. The task was achieved through a combination of teleoperator controls and automatic step climbing.

Operator Control. The teleoperator begins by positioning ODEX I in front of the truck's tailgate and activating a step-climbing addendum to the normal walking program using a joystick control unit. The teleoperator assists the functionoid in initially finding the exact location of the tailgate edge.

From that point, the functionoid walks up the step under complete teleoperator control for horizontal motion and under totally automatic control for negotiating vertical motion. The descent from the truck is performed in the same manner.

We "paper trained" the functionoid to verify the algorithms for this routine. That is, before we had it actually climb into a truck, we took a large piece of paper and made a drawing of the truck bed. Placing this model on the floor resulted in a successful rehearsal of the routine the first time we used the vehicle.

On each articulator is a decal with numbers 0 through 5 for ease of teleoperator identification. These numbers play a role in a further example of agility and maneuverability: we use one of the articulators to adjust a swivel ring on top of a pedestal, put its crutch tip through the ring, then lift the pedestal.

To accomplish this, the teleoperator selects the desired articulator and enters the number with a thumb-wheel switch on the control unit. The operator chooses the algorithm for this "articulator mode," then simply uses the joystick to move the articulator horizontally, and then adjusts the stepping height knob for vertical movement.

ODEX I's ability to change directions in mid-stride and to rotate while moving required extensive research. Ironically, these feats of agility demand very little of the teleoperator. To rotate the system while it is walking, for instance, the teleoperator

must only adjust the rotation rate knob on the joystick control unit to have the system gyrate to the left or right.

The functionoid's ease of operation is noteworthy. The teleoperator presently is concerned only with 10 switches and knobs and a joystick. Future functionoids will have simpler controls.

Strength. Our ability to add strength to the functionoid was a milestone. A walking machine must be very strong simply to lift its own weight. The machine is under tremendous stress when merely extending articulators to take a step.

The more weight placed on a machine like the functionoid, the more power is required, and some agility could be lost. We wanted to ensure that, when functionoids start supporting heavy payloads and performing heavy lifting tasks, agility will not be impaired.

The best example of the functionoid's strength was demonstrated last March when we put ODEX I in a squat profile behind a pickup truck rigged with a special lifting bracket. The functionoid raised itself on three legs and lifted the back end of the 2200-pound vehicle. It then proved itself equally strong in the normal profile as it walked across the floor, turning the truck's position 90 degrees.

ODEX I can carry a maximum load of nearly 2100 pounds (5.6 times its own weight) while in a stationary position with all six articulators on the ground and nearly 900 pounds at normal walking speed (2.3 times its own weight). The load capacity of any one articulator while the unit is operating is 400 pounds.

ODEX I is the first walking machine in which strength-to-weight ratios are thought of in multiples of unit weight. Its strength is maximized because ODEX I practices concepts a person would use to lift a heavy load.

ODEX I assumes a wider profile for stability while lifting, and the weight is centrally located on the primary structure for greatest capacity. During the truck-lifting demonstration,

the teleoperator shortened the stride length for better weight distribution.

Since we wanted a machine that could traverse rough terrain and perform other necessary tasks, we designed a functionoid that could maintain a very stable platform. ODEX I's stability is achieved primarily through use of a rigid leg structure with active suspension. Should it stop on the side of a hill, the system would lock the articulators and remain very stable.

Self-contained power, the final milestone we wanted to achieve with ODEX I, was completed early in the development cycle with the installation below the primary structure of a standard 24V, 25 amp-hour aircraft battery.

ODEX I runs on 450 watts and requires a recharge after about one hour of normal walking. When the system stops, the teleoperator can shut off all power except a "wake up" circuit. ODEX I draws only 2 watts when in this stand-by mode. We are currently looking at alternative power sources to extend the power ranges, but for the purposes of the capabilities model, we had all the power we needed.

Other attributes of ODEX I include ease of repair due to the use of modular parts. An entire articulator, for example, could be changed within an hour. The functionoid's circular design makes it omnidirectional. The design also provides complete articulator overlap capability. Each leg can enter another leg's zone of operation.

The articulators have a folding mechanical attribute as well. ODEX I can assume a tucked profile, because one section of an articulator can fold into the operating area of another section of that same articulator.

The circular design distinguishes the functionoid from other walking machines. Previously, most walkers featured articulators stemming from a long, rectangular primary structure.

As we were building a prototype of a very advanced technology, almost all of the mechanisms for ODEX I were custom-made. We created the design, and in most cases, even constructed these mechanisms ourselves.

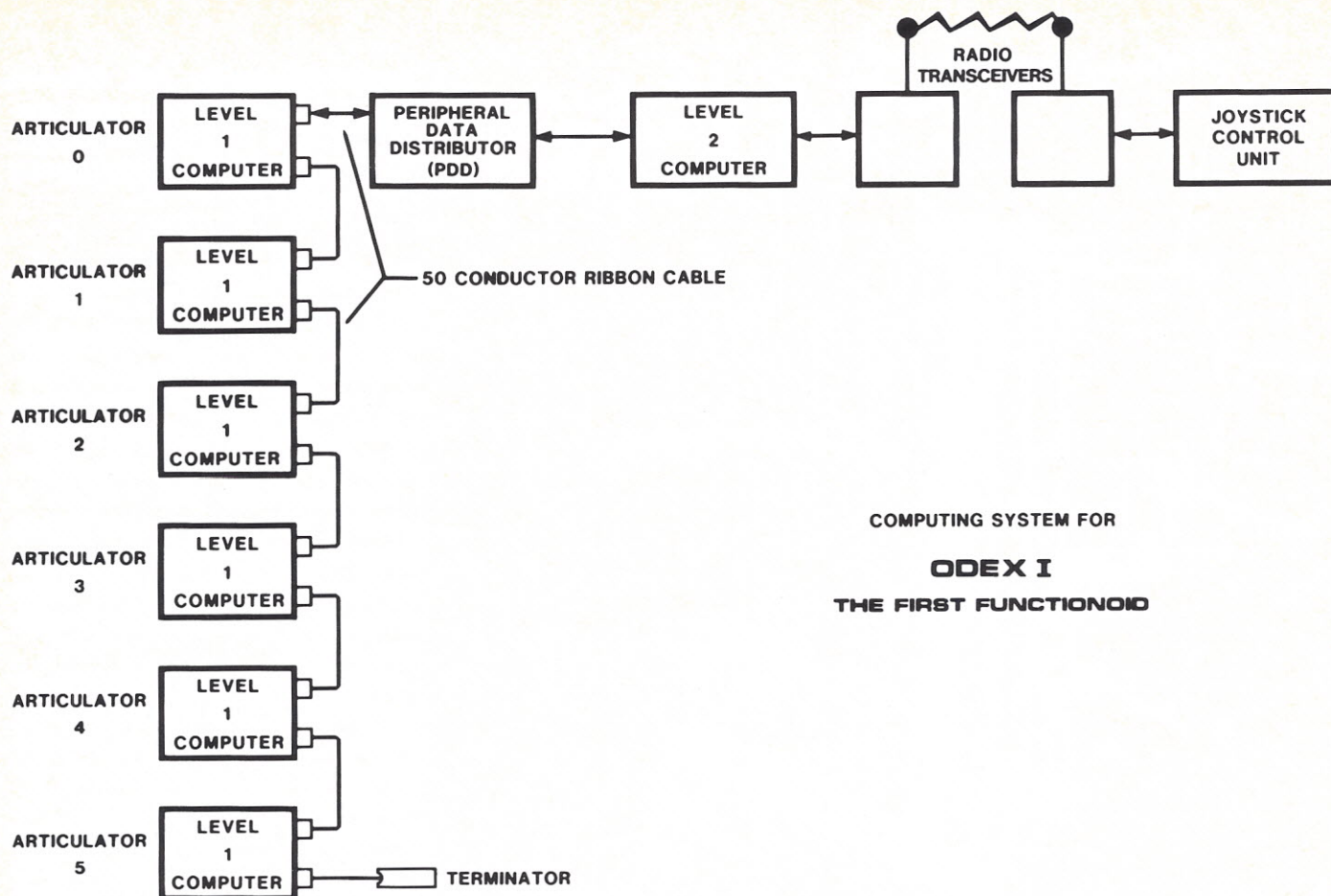


Figure 1. ODEX I has six computers referred to as "level 1" computers—one for each articulator. A peripheral data distributor (PDD) communicates to these computers via a 50-conductor ribbon cable, daisy-chained and terminated at the last articulator. The PDD conducts the data flow to an on-board "level 2" computer through an interface. This level 2 computing system accepts commands from the joystick control unit and computes the required articulator motion using algorithms developed in-house. The joystick control unit communicates with ODEX I's computing system through a radio link.

Control Computers. Odetics also designed the functionoid's computing system. ODEX I has six level 1 computers, one for each articulator. Each computer features three circuit boards.

One circuit board provides status reports for the higher computer level and accepts and interprets commands for actuating the articulator motors. The other two are servocontroller boards, which accept instructions from the first circuit board and exert direct control over the articulator.

A peripheral data distributor (PDD) communicates to these computers via a 50-conductor ribbon cable, daisy-chained and terminated at the last articulator. The PDD conducts the data flow to an on-board "level 2" computer. This level 2 computing system accepts commands from the joystick control unit and computes the required articulator motion using

algorithms developed in-house. The remote joystick control unit communicates with ODEX I's computing system through a radio link.

We were able to develop and test the level 1 computing system, the actual servocontrol, before the higher level software was completed. The entire software package was completed in 10 months.

This software uses extensive assembly language and some high-level language to incorporate the algorithms we developed for mobility. We also created the computer hardware system, using off-the-shelf microprocessors and integrated circuits.

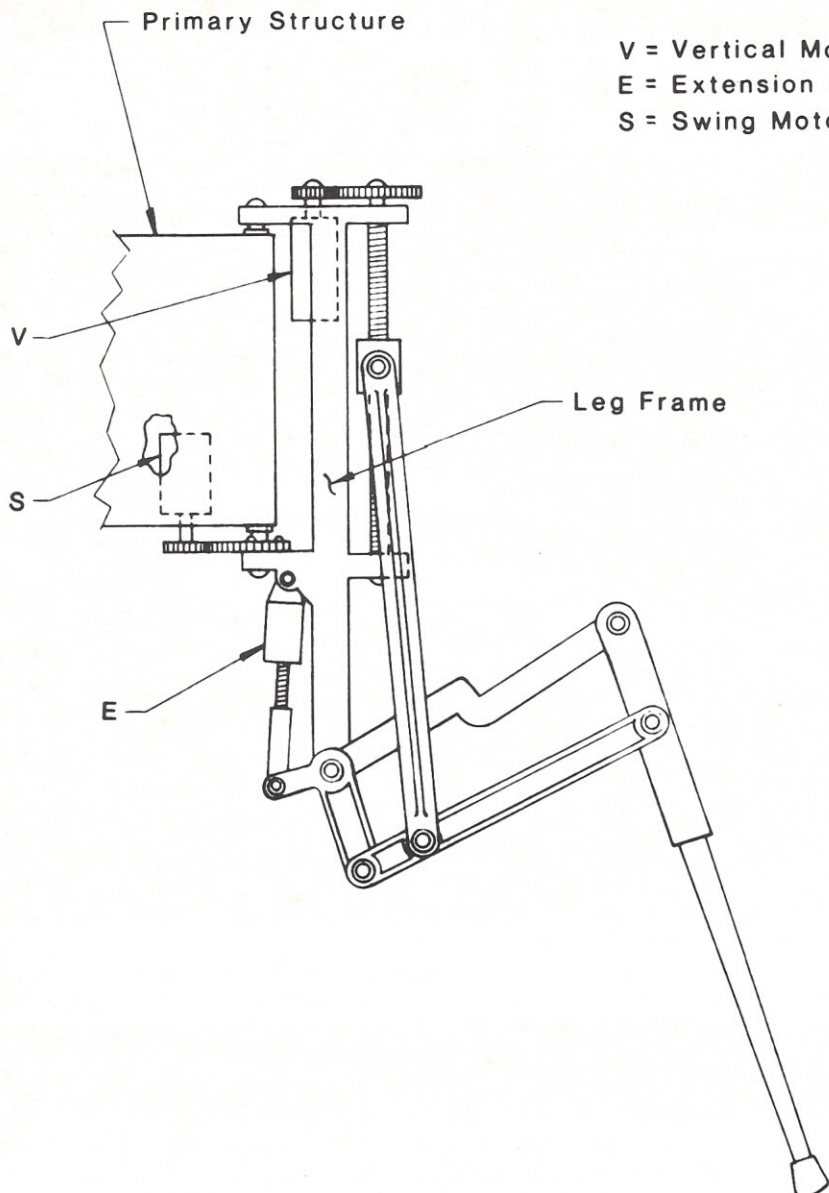
Development. Although all the actual work required to build the first operational functionoid was done in less than 18 months, the idea for this walking machine was first conceived more than 10 years ago. The funds

needed to proceed with development, however, were not available until Odetics became a publicly-held company in July 1981. A few months later, the board of directors authorized the first phase of ODEX I's development.

We put together our research and development team of mechanical and electrical engineering and computer science experts and leased space for an operations center. By June 1982, we had successfully tested an operating articulator.

By September, we had created a teleoperated machine with an umbilical cord that served as the communications link between the remote higher level computing system and the lower level computers on-board ODEX I's primary structure. We also achieved self-contained system power.

At this point, the functionoid looked



V = Vertical Motor
E = Extension Motor
S = Swing Motor

Figure 2. There are 18 motors on board ODEX I, three associated with each articulator. The largest of the three dictates vertical movement. The other two are identical, controlling extension and swing.

like the capabilities model we demonstrated at the March unveiling, except for the umbilical cord and an empty 10-inch span on top of the primary structure. The electronics package was eventually placed here. During phase 2 of ODEX I's development cycle, we completed the difficult goals of removing the umbilical cord and placing the level 2 computing system on-board the first functionoid.

ODEX I and a twin unit, ODEX II, were designed specifically to demonstrate the capabilities discussed in this article. The next generation functionoid will have other attributes designed to study its feasibility in different environments. Vital mecha-

nisms and electronics will be sealed against the elements to prepare ODEX III for environmental testing.

We eventually want ODEX III to be autonomous, receiving only very general orders. We would like ODEX III to be able to proceed to an ordered position by picking and negotiating its own route.

Both autonomous and teleoperated functionoids will require accurate vision systems, not only for indoor applications such as nuclear power plants and security, but also for the exploration of different planets.

A future vision system might include stereo television with optical-ranging and ultrasonics to help de-

termine dimensions and distances and perceive objects in the functionoid's line of sight. In addition, we hope to develop tactile sensors for the articulators.

Conclusion. Our decision to develop the first functionoid has been a rewarding one. James M. Beggs, administrator of the National Aeronautics and Space Administration, a customer of our Spaceborne tape recorders, wrote us shortly after the ODEX I announcement that, "NASA is proud to be associated with private sector firms which are willing to pay the price and to take the risks necessary to bring about advances such as this."

We believe that when historians recount the evolution of walking machines, Odetics' research will be considered an important part of the development of this technology. The functionoid also makes excellent business sense. The price we will place on future functionoids will vary with the embodiment, form, and applications they will be used for, as well as with the quantity ordered. Odetics expects to market functionoids directly and use joint venture licensing agreements.

We will bring to the market a tool that will allow humans to go places and do things that until now have been unsafe or impossible. This machine will help us achieve what we originally intended to do: help our company enjoy continued growth and competitiveness. □

About the Author:
Marvin Russell, Jr.
is director of engineering at Odetics, Inc.



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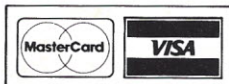
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Robot factories need robot transport. Something has to carry raw material to all those 7-degree-of-freedom robot arms, and finished products need to get to the shipping crates. The necessary machines are mostly large (payload of 50 pounds) and expensive (over \$10,000). Small firms, in light industry doing batch work, generally do without robots. One reason may be the lack of inexpensive, low-cost robotic transport.

Transport Methods. A variety of machines are used to move things about in a plant. Among them are conveyers (including programmable conveyers), hand carts and small trucks (including complex robot controlled vehicles), and tracked vehicles constrained to run along a network of fixed guide rails. Each of these transport systems has advantages and disadvantages, either in cost, flexibility, or accuracy. Some are more useful in automated factories than others.

An Ideal Transport System. By definition, automated transportation runs without human intervention, at least for routine operations. To replace people, a robotic transport system must do what people do, better (in some way) than people.

What do people *really* do in factories that makes them difficult to replace? Last year, I arranged to visit

a number of small assembly plants in the San Jose, California area. Several were printed circuit board manufacturers, employing about 15 to 30 people. For potential roboticists, these visits have much to recommend them: ideas for robotics applications accumulate with each one.

Firms of this size live on batch jobs—making from a few up to several thousand of one kind of printed circuit board and often different sizes and kinds at a time. They are not like the large electronics manufacturers, which can amortize hard automation over millions of identical pieces.

In a small PC board plant (and in other assembly plants where I have worked or visited) people perform at least two essential services on the plant floor:

- People *fetch* things. They know where things are, and they get them and bring them to the right place at the right time.
- People *align*, affix, or otherwise bludgeon parts into position relative to other parts or tools.

In addition, people detect faults and know what to do when they find them.

In a typical batch PC board company, more than half the work force is involved with fetching (getting the bulk PC board material) and alignment (placing it in the numerically-controlled router). A plant transport

system must mimic this human capability. It must know where things are and when and where to take them (fetching). A manipulator must place parts onto and remove them from the system (alignment).

A good transport system usually has three functions: controller, transporter (vehicle), and manipulator. The manipulator function can be part of the robot work cell, or it can be part of (or mounted on) the vehicle.

The Importance of Alignment. For a robot or tool to manipulate a part arriving on the transporter, it must know where the part is located. There are two basic ways it can know this: it can use sensors to search for and locate the part, or it can operate blindly, depending on accurate alignment of the transport system.

A typical part at a work station must be aligned and positioned to considerable accuracy. It makes sense not to throw away this alignment when the part is placed on the transport system. Alignment and positional accuracy are effectively products of the plant as much as the PC boards or widgets that go out the door. If you throw alignment away you must restore it at the next work cell. This restoration requires sensors (expensive), machines that sort or place (expensive vibrating sorters), or people (also expensive).

The transport system, if possible, should carry information (in this case parts orientation) along with the part. This requirement constrains the type of carrier you can choose. The major constraint is a stable platform for holding objects securely.

Fixed Track Vehicles. A good solution for this transport problem is a vehicle that runs on fixed tracks or rails. The prototype of this tracked system is the model railroad train. I think a computer-controlled model train would make an excellent project for a low-cost experimental robotic transport system. In fact, it might even be practical for light-duty commercial use in some applications.

The main problem with model railroads, apart from limited payload and reliability, is the difficulty of achieving accuracy in the fore-aft direction. Lateral resolution (positional accuracy) depends on track placement and slop in the wheels and undercarriage. It can be as good as a few thousandths of an inch.

Fore-aft resolution requires the addition of a position encoder to keep track of wheel revolutions. There is no simple way to account for wheel slippage and skidding, however, particularly if gradients are encountered. While these errors are not great, they accumulate with time and result in a drift in indicated position. The only way to overcome the problem on smooth-wheel vehicles like trains is to use an external positional reference to continually update or "zero" the encoder.

Cog-Wheel Drive. This slippage problem is eliminated with the use of a cog-wheel drive. This drive system consists of a drive gear on the vehicle, which meshes with a toothed track. Cog-wheel drives are nothing new; they have been used on railroads since the last century to prevent wheel slippage of the engine on steep grades (see photo 1).

I have developed a transport system that uses this drive system. The result is a simple, sturdy robot vehicle that ought to be suitable for many transport tasks. It is simple and

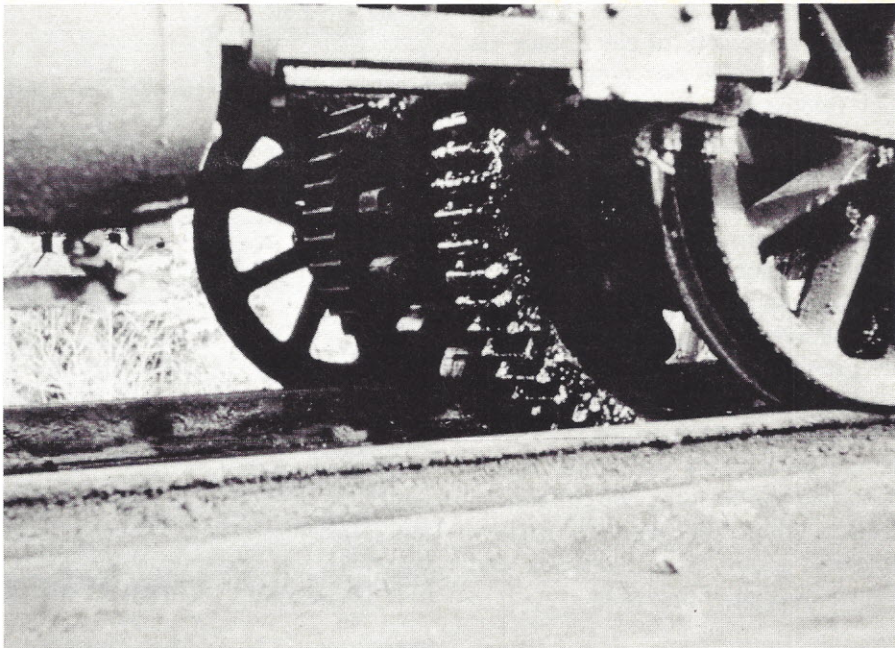


Photo 1. View of the cog-wheel system used on the first mountain climbing railway in the world. This railway is located on Mt. Washington in New Hampshire. The cog-wheel system enables the engines to climb an average grade of 25 percent over 3½ miles. The steepest incline is 37.41 percent. Photo courtesy of Trask's Studio and Mt. Washington Railway Company.

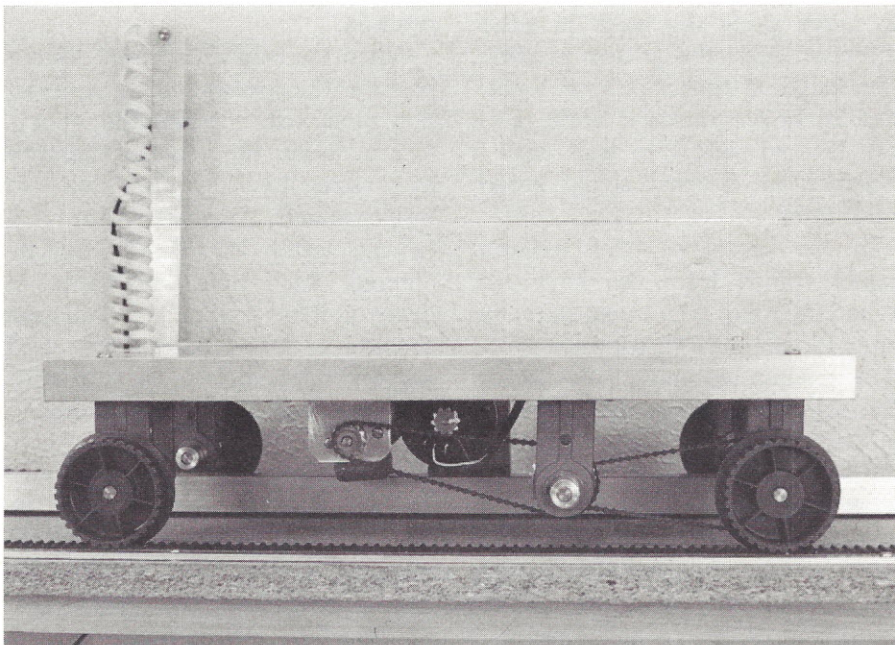


Photo 2. The robot cart. The coiled wire carries only the encoder signals. The motor drive sprocket is to the left on the chain. The encoder is visible to the right of the motor.

cheap enough for a home or school project but so far has proven to be sufficiently reliable and accurate to merit consideration for light industrial applications.

General Description. The robot is a four-wheeled cart driven by an on-

board DC gearmotor (photo 2). Vehicle position is monitored by an on-board rotary position encoder, which detects rotation of the vehicle wheels. Control and interface electronics and power supplies are off the vehicle.

I use the Apple II computer to con-

trol the robot. The Apple II is connected to the control electronics via two 8-bit parallel ports: one for output (motor speed/direction control) and one for input (encoder position).

The cart runs on a cog-track system made of parallel automobile engine timing belts stretched flat and glued onto aluminum strips. The aluminum can then be mounted on any flat surface. Power for the drive motor can be provided either by trailing wires or by a power track with brushes on the vehicle. For the prototype, I used N-gauge model railroad track mounted between the two rubber cog tracks (photo 3). This is quality material made of nickel-silver and shows no sign of oxidizing.

Vehicle Operation. Programming and operating the vehicle is simple. I have taught a number of people to use the system in less than half an hour. The robot can be programmed to move along the track in either direction and stop at any position. The length of time it stays at a position can be programmed, or the robot can be told simply to wait until it receives an external signal before continuing.

In the prototype, this external signal comes from the keyboard. When the robot is in a wait state, the operator can make it continue to the next position by typing R (for RUN). The signal could as easily come from any external source, such as the robot work station where the cart is located, or from a central control computer. This "continue" signal provides a method for coordinating the motion of the robot cart with the operations of the rest of the plant.

The Robot Operating System (ROS). The robot operating system, written in 6502 assembly language, is divided into two parts: TEACH and RUN. The operating system automatically starts in the TEACH mode. In this mode, the operator can move the robot to the different locations either manually by pushing the cart, or by pressing the arrow keys on the keyboard. These keys turn the motor on briefly in the forward or reverse

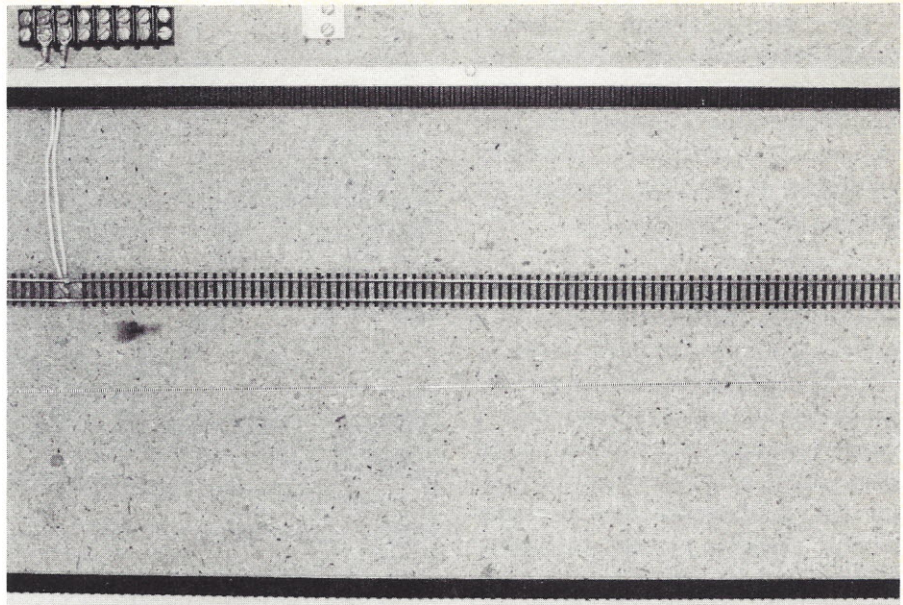


Photo 3. Power is provided to the robot cart through brushes riding over a nickel-silver N-gauge track. Power could optionally be transmitted through a coiled wire.

direction. Repeatedly pressing these arrow keys drives the robot to any position.

When the robot reaches a desired position, the operator enters this location, along with the time the robot is to wait there, into program memory by pressing the S key (SET), followed by a time unit. Time units from 1 to 9 or the letter W (WAIT) can be entered. Each time unit causes a delay of about 2 seconds. A program consists of a set of positions and associated time delays. Up to 31 positions may be saved for any program.

Robot Operation. To run the program you have just entered, press the R key. This resets the program memory to the first position you entered and moves the robot to that position. The cart then goes to each position sequentially, waiting at each location for the programmed length of time. When the robot reaches the final programmed step, the program resets to position 1, and the robot repeats the cycle. If the time stored at a position is W, the cart remains at that location until the R key is pressed.

Zeroing the Encoder. When the operating system is first entered, a value of hexadecimal 50 (decimal 80) is stored in program position mem-

ory. This number represents the cart position. It is updated (incremented or decremented) by the position encoder logic which monitors the rotation of the robot drive wheel. Since the cart can be in any position when the power is turned on, the position should be reset or "zeroed" before you enter a program.

Zeroing can be done at any time, in either the RUN or TEACH mode. By triggering a remote switch located on a post on the rail platform, hexadecimal 50 replaces the current value in program position memory.

The ability to zero the position at any time allows the possibility of automatic zeroing. A simple way to accomplish this would be to replace the toggle switch by a microswitch or other switching device set in the path of the vehicle. Each time the robot passed the switch location, the switch would be triggered.

Screen Format. A video display driver provides key information about the robot to the programmer. The following information is provided (photo 4):

- basic command instructions
- operating state status (RUN or TEACH)
- position of the robot
- time at the position.

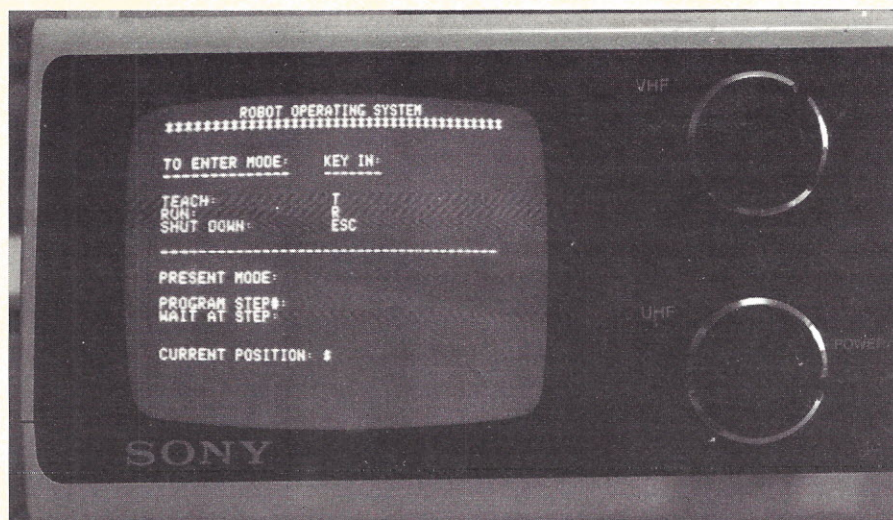


Photo 4. Robot operating system (ROS) screen format. A program can have up to 31 separate position steps. Time at each position is programmable.

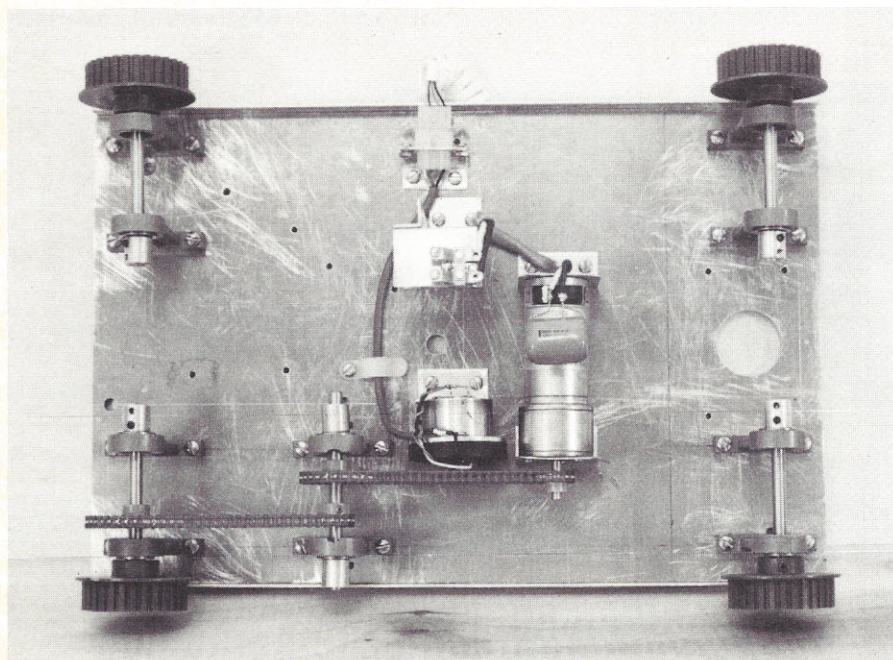


Photo 5. Vehicle construction. Wheels are timing belt pulleys on 1/4 inch shafts and ball bearing hangers. The plug at the top brings power to and signals from the shaft encoder (next to the motor). Note the brushes and the large (1μf) capacitor on the motor. The capacitor is necessary to reduce noise on the encoder line.

Mechanical Hardware. The vehicle's construction is very simple (photo 5). The major components consist of the frame, wheel assembly, drive chain, shaft encoder, and motor. Power for the motor is taken off the central track with brushes mounted on the cart. A wire assembly brings power to the shaft encoder and takes encoder signals from the vehicle to the computer.

The vehicle frame is a piece of 1/4 inch aluminum to which all assem-

blies are mounted with machine screws driven into holes tapped into the frame. The drive motor is a Pittman 24 VDC gearmotor with a 10:1 reduction gearbox. Power is taken to the wheels in two reduction stages, yielding an overall ratio of about 60:1. Each vehicle wheel rotation drives the vehicle exactly 6 inches.

Top speed is about 9 inches/second. At this gearing, the motor has no trouble driving the vehicle with payloads of more than 5 pounds.

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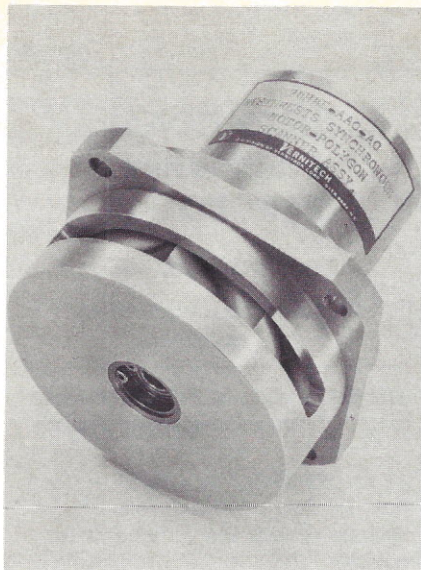
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The DC servomotor/shaft encoder is not the only solution for powering small robot vehicles. One reason I used this combination was that I had all the parts left over from another project. One drive option would be using a stepper motor. Steppers use less hardware, since they can be driven and accurately positioned without position feedback (open loop) provided you can be sure that the payload range is never exceeded. The disadvantage of using steppers open loop is that the position of the robot is defined (by the computer) as being equal to the number of signals sent to the motor. If something impedes the vehicle so it can't move when a signal is sent, the stored robot position is inaccurate.

Electronics Hardware. Besides the Apple II computer, the robot control hardware includes a parallel interface, logic hardware board, 5V power supply board, motor power amplifier board, a 14.5 VDC 10 Amp motor power supply, and the shaft encoder (photo 6). Hardware for the encoder and motor control logic, 5V power supply, and motor power amplifier, is located on three experimental perf boards (photo 7).

Parallel Interface. The I/O channel for all signals between the computer and the robot is the parallel interface board, from John Bell Engineering, which plugs into slot 3 in the Apple's expansion interface. This board has two separate 6522 versatile interface

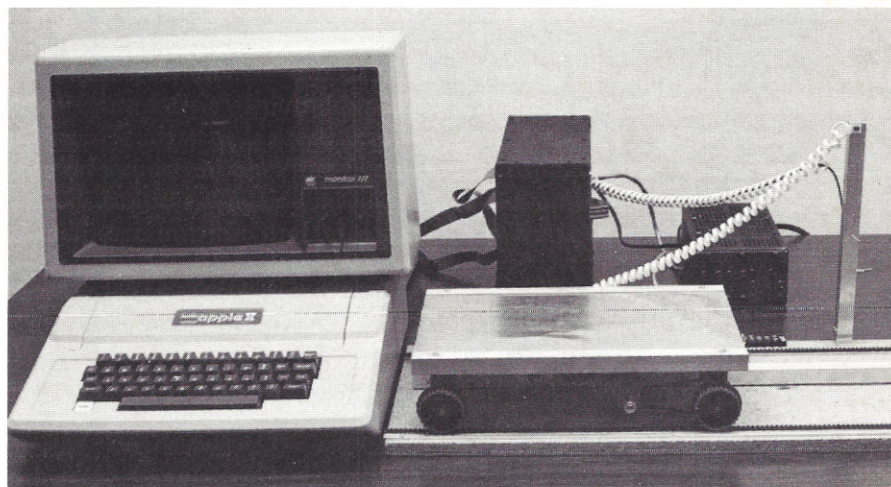


Photo 6. Electronics hardware. From right: motor power supply, case for control logic boards. The Apple II computer serves as the controller.

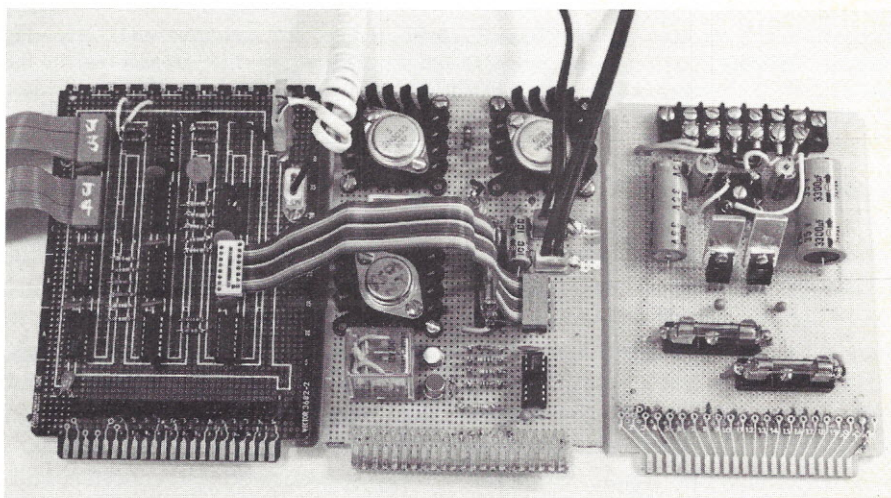


Photo 7. From left: logic hardware board (motor speed control and shaft encoder logic), motor power amplifier board, logic level power supply (± 5 VDC).

adapter (VIA) chips. Each 6522 has two 8-bit parallel ports. The 6522s have useful features, such as 16-bit programmable timers.

I channeled all control and data signals through one of the 6522s, with one port reserved for output and one for input. In addition, I programmed the chip to provide interrupts (through its programmable timer) to the computer. At each interrupt, a software routine checks the encoder and updates the cart position in memory. Ribbon cables make the connection between the Apple parallel board and the logic control board.

Logic Board. The logic board contains the control logic for the motor speed/direction control and for the encoder signal transformation.

Motor Speed/Direction Control Logic. The motor speed is regulated by a pulse width modulated (PWM) duty cycle speed control device. The PWM speed controller produces a rectangular wave at a constant frequency, such that the output voltage snaps between full on (5V) and full off (0V). You can vary the percentage of time the voltage is high (duty cycle). This signal is sent to the motor amplifier. The motor effectively integrates the signal so the apparent voltage it "sees" is proportional to the duty cycle.

The advantage PWM controllers have over analog controllers is that they are easy on the power transistors in the motor amplifier. The transistors are always either turned fully off (no current flowing through them) or fully on (minimum voltage drop across them). When transistors operate in the intermediate range, they act like variable resistors and, like resistors, dissipate heat. My power amplifier transistors always run cool to the touch, no matter how hard the motor works. An abbreviated schematic of the motor control system is shown in figure 1.

Two chips compose the heart of the PWM controller: a digital-to-analog converter (DAC 0806) and an analog-to-digital converter (TL 507). The

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SONIC POSITION MEASURING

The diagram illustrates the Sonic Position Measuring system. A mobile unit with three transmitters (labeled 1, 2, and 3) is shown on a track. A table with various objects (cylinders, cubes, spheres) is positioned in front of it. A control unit, labeled UPM104, is connected to a display unit, labeled CGR104. The UPM104 displays coordinates (X, Y, Z) and a scale. The CGR104 displays a 3D coordinate system with axes X, Y, and Z, and a scale.

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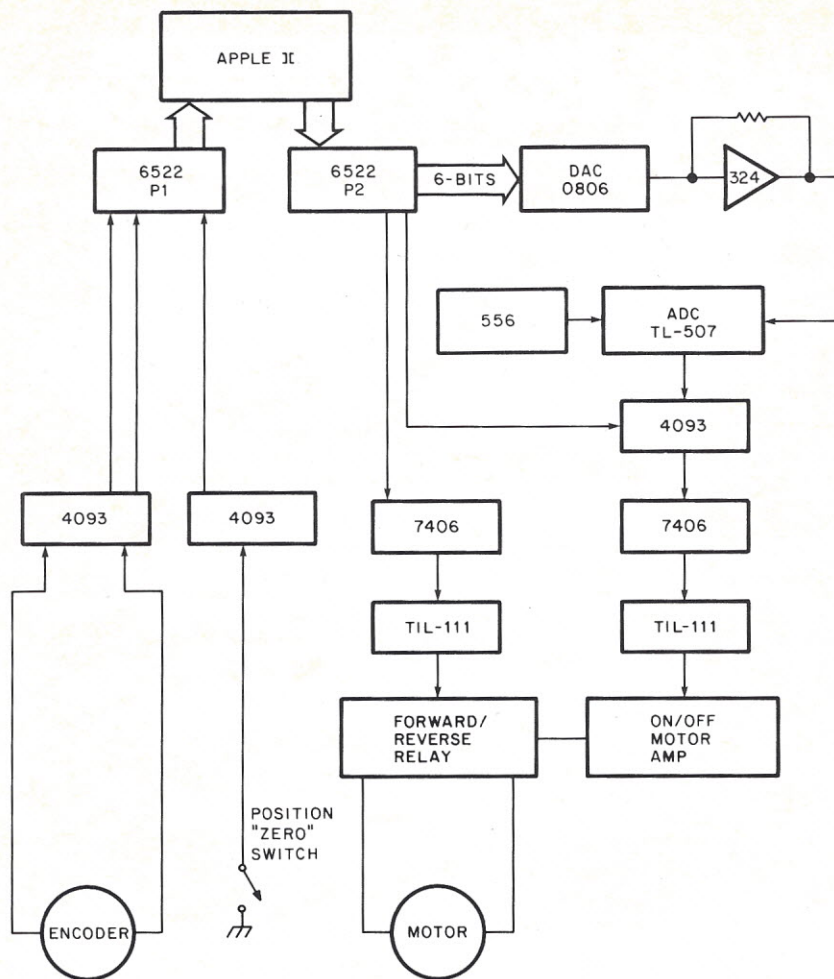


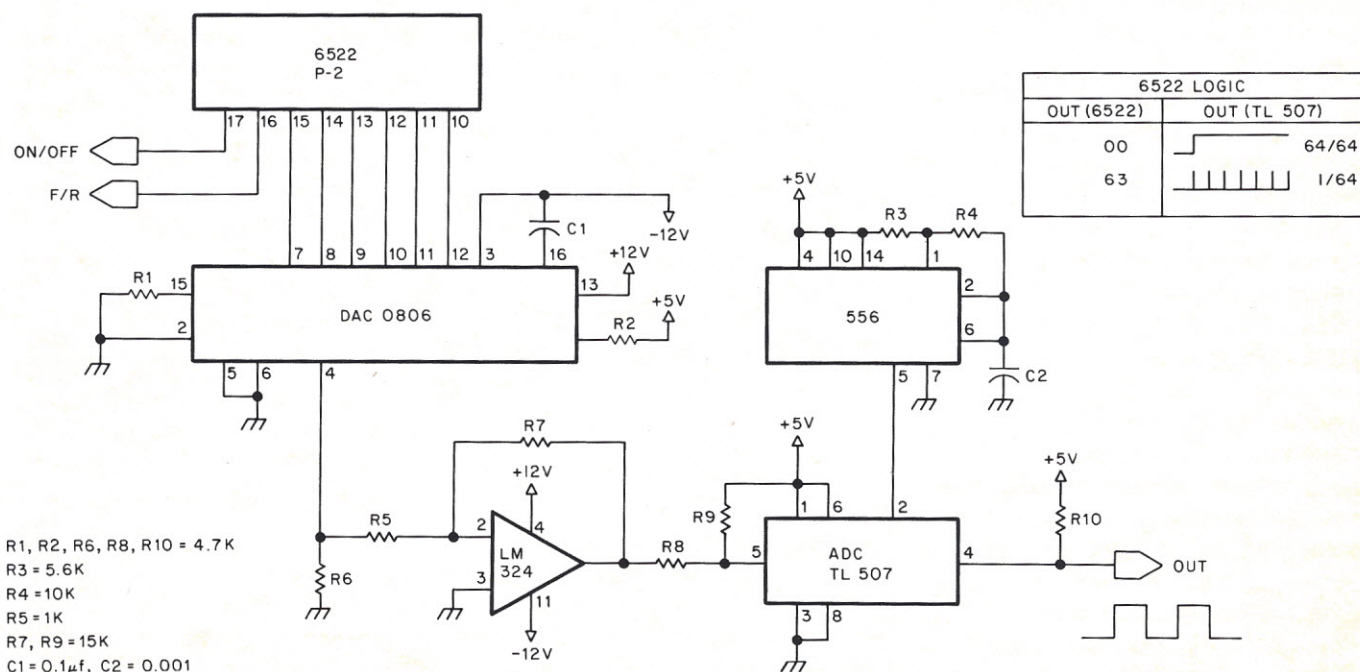
Figure 1. Motor control and encoder logic hardware layout showing signal flow.

basic idea is to take 6 bits of the parallel port from the Apple II into the DAC (DAC 0806). The output of the DAC circuit (64 possible voltage levels) is fed into the ADC (TL 507). The output of the ADC is a duty cycle, which varies nicely between 1 (fully on) and 1/64. The relevant part of the circuit from figure 1, is shown in more detail in figure 2.

You may have to fiddle with the ADC resistor values, and with the feedback resistors across op-amp LM 324 (R7-R9), to achieve the full range of duty cycles. The 556 is configured as an astable multivibrator (the source of the constant frequency pulses). The duty cycle signal is passed to a 4093 CMOS NAND gate, where it is logically combined with the on/off bit. The on/off bit allows positive on/off control without speed adjustment.

The two remaining bits of the 8-bit parallel port (P2) are reserved for the on/off and the forward/reverse signals. The 7406 is a TTL inverting

Figure 2. Pulse width modulator control circuit. There are many ways to implement this function, and this one uses relatively little hardware. R10 is a pull-up resistor needed for the CMOS (4093) interface. Duty cycle (percentage of time the output voltage is high) can be varied from $1/64$ to 1.



driver, which will sink sufficient current to power the opto-isolator (TIL-111). Opto-isolators do two things: they isolate the relatively delicate logic from the high power motor lines, and they afford a very easy method of amplifying the logic level (5V) signals to motor level (14.5V).

The forward/reverse bit also is optically isolated before going to the double-pole double-throw relay. The function of the relay is simply to change the polarity of the voltage go-

ing to the motor. I used it in this application because it is simpler and cheaper (reduces transistor count) and because it is more efficient (no voltage drop across a relay).

Encoder Logic. The shaft encoder consists of a cup with a shaft through it; on the shaft is a plastic disk that is transparent over 180 degrees and blackened over the other half. When the shaft turns, light from two LEDs is alternately blocked and transmitted to two corresponding phototran-

sistors. These two signals are squared off (made rectangular in shape) by the 4093 Schmidt-trigger NAND gates and are sent to the input parallel port (P1) on the 6522. A third line, from the absolute-position switch, also follows this route (figure 1). Whenever this switch is activated, the ROS software enters a value of hexadecimal 50 into cart position memory.

Relays. Despite criticism from my hi-tech friends, I think relays are great for low-frequency applications like this. The problem with relays is that they are much more electrically noisy than transistors and should be kept away from dainty signals such as those coming from the shaft encoder. Changing direction on the cart initially caused position errors in the cart position memory. A look at the shaft encoder signals on the oscilloscope confirmed that when the relay switched, huge glitches propagated up the encoder signal lines. I reduced these spikes to a fraction of a volt by running twisted pair wires from the encoder and by adding a nonpolarized 1 μ F capacitor across the motor terminals on the cart, in parallel to a smaller one at the relay (photo 5).

Software. The master flowchart for the robot operating system (ROS) appears in figure 3. The software consists of a short BASIC program, which formats the screen and loads the main program body (written in 6502 assembly language which begins with the INIT block). The program can serve as a good prototype for simple robot operating systems; it has all the essential parts and has so far been successful and error-free.

INIT has a "housekeeping" function. It defines and initializes all variables, sets aside memory for utility registers and tables, and initializes the ports and timer on the parallel interface. It also sets up the interrupt vector addressing, so that when program interrupts occur, a jump is made into the ENCODER routine.

WAITINT is a conditional endless loop, which is simply a place to stay until an interrupt occurs (listing 1).

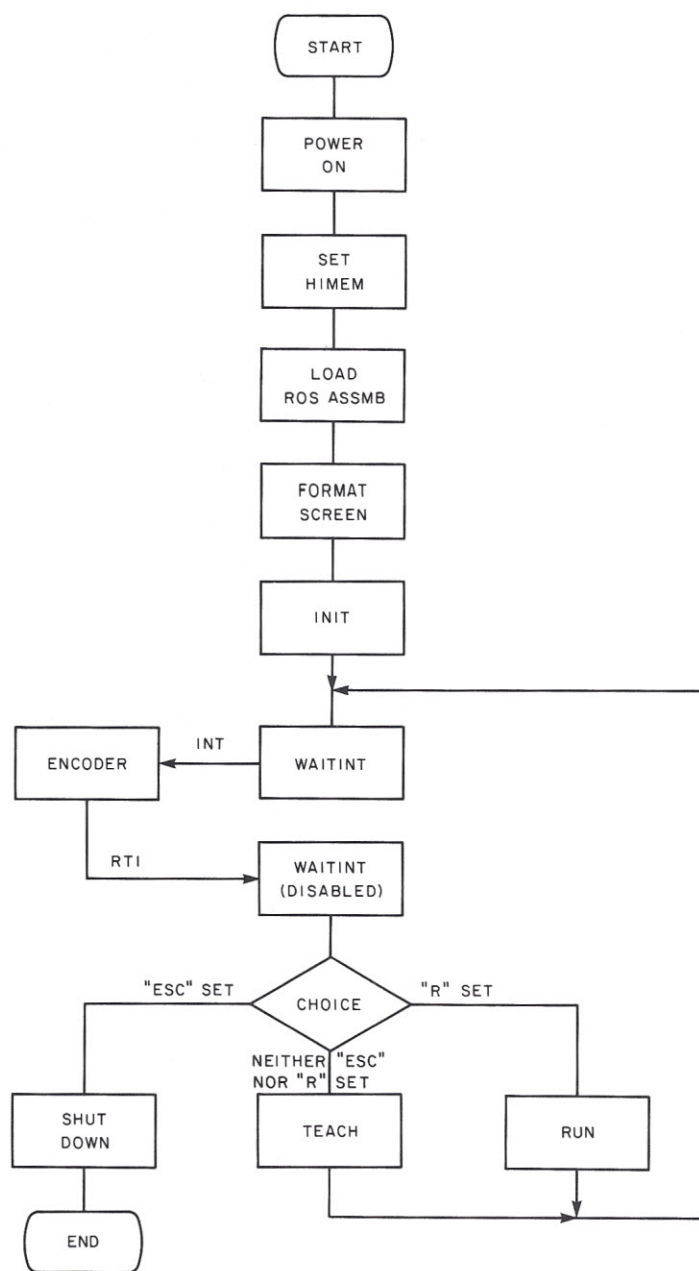
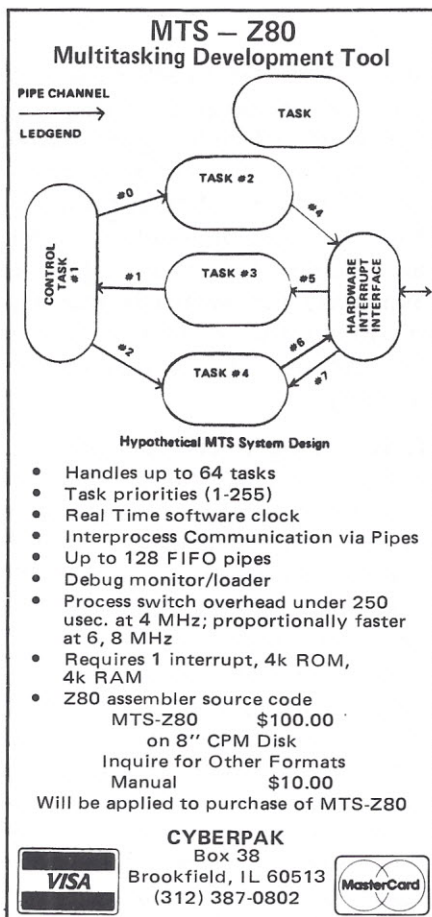


Figure 3. The master flowchart for the robot operating system.



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When an interrupt occurs, the program jumps to the ENCODER routine. Before it leaves ENCODER, variable WVAR is set to 01. When RTI (return from interrupt) is executed, and WTLOOP is reentered, the compare instruction does not result in a match, and the loop is exited.

ENCODER measures the encoder status and notes if any change has taken place since the last measurement. If it has, the cart position memory location is either incremented or decremented, depending on whether the new encoder value indicates forward or backward cart motion. Since the software works by reading the current state of the two encoder bits (as stored in the input port memory buffer), and not by reading edge-transitions from state to state, there is no danger in missing a change in cart position.

To ensure encoder changes are not missed, the interrupt rate is set at 120 Hz, and the maximum encoder change rate at top speed is about 43 Hz. The encoder bit states, therefore, are checked twice before both bits can change.

CHOICE checks whether the T (TEACH), R (RUN), or ESC (ESCAPE) keys have been pressed, or whether the ASCII code for R or T has been stored in the status register. This decision point is checked each time, after the program leaves the ENCODER routine (at 120 Hz). The INIT routine

sets the status register to T, so that the TEACH routine is entered automatically on start-up

TEACH and RUN have been previously described. Their major functions are to store and read from position/time tables. The RUN routine contains a servo subroutine, which moves the cart towards the next set position and stops at the location stored in TEACH.

CART SERVO is a modified position servo. In operation, the routine measures the difference between actual cart location and desired location (the next position set-point). In an ideal position servo, the power is reduced as a function of "closeness" to the desired position:

$$V = K(Pa - Pd), \text{ where}$$

V = Voltage to the motor

K = Empirical constant

Pa = Actual position

Pd = Desired position

In such a servo, the power is reduced as the cart approaches its goal. In my robot, the servo has been optimized, as follows:

- If $|Pa - Pd| > 20$ hexadecimal (32 decimal), then $V = V_{max}$.
- If $|Pa - Pd| < 6$, then $V = 6$ (Actually $\frac{6}{64}$ of V_{max}).

The voltage setting of 6 produces sufficient power to nudge the cart to the next encoder position without overshooting.

I originally intended to use a modified PID servo (proportional-integral derivative), but found that the optimized positional servo I used

```

; WAIT FOR INTERRUPT
WAITINT  LDA  #$00
          STA  WVAR
          STA  WVAR
WTLOOP   LDA  WVAR
          CMP  #$00
          BEQ  WTLOOP
          ; FALL INTO CHOICE ROUTINE IF WVAR <> 00
          ; END WAITINT

```

Listing 1. The wait loop expects an interrupt routine to change the value of WTLOOP and indicate when the loop can be exited.

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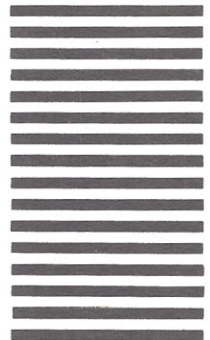
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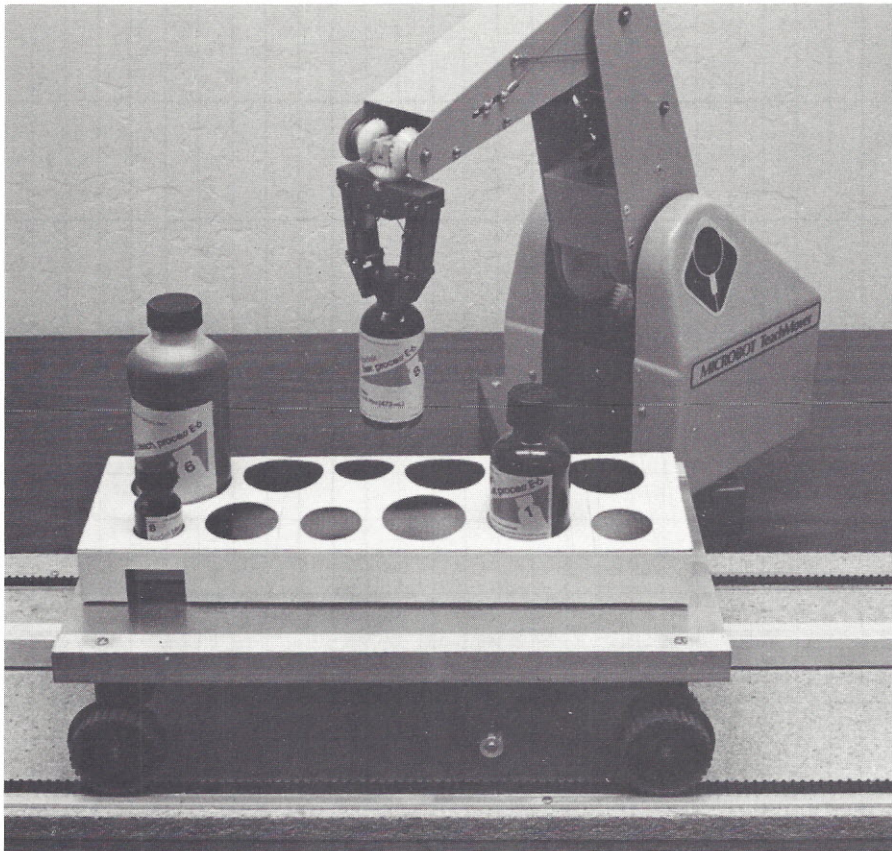
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The positional resolution of the vehicle was about 0.2 inch. For greater resolutions, there would be a tendency to overshoot when incrementing the vehicle close to the endpoint, using the present servo. At higher position resolutions, it might be useful to add a integral function to the servo, or go to a modified proportional-integral servo, rather than a proportional one.

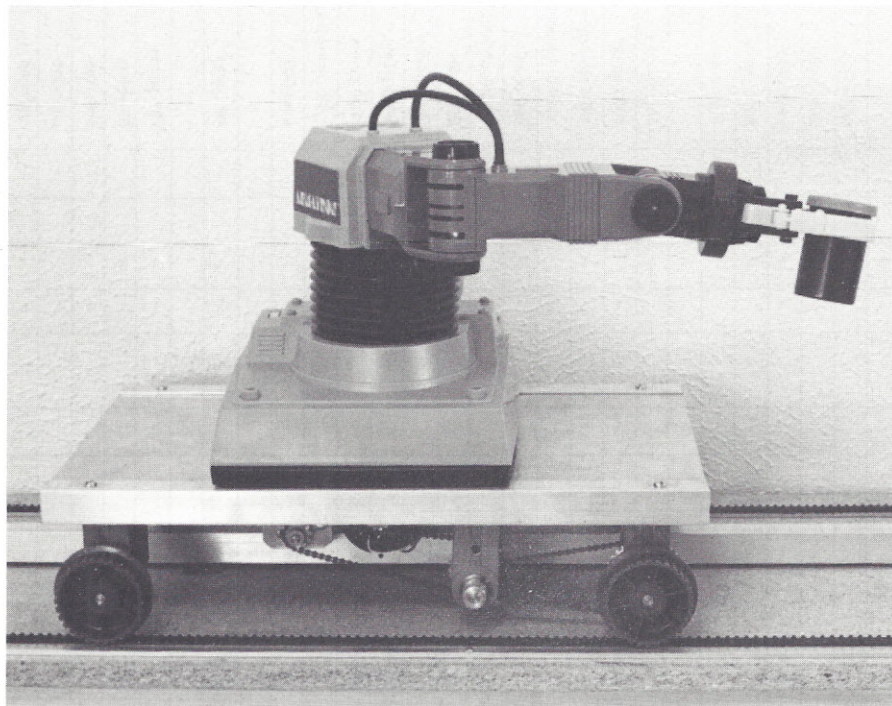
The effect of this servo would be to incrementally add power to the motor for each time unit that an error exists, thus allowing the cart to creep up on the endpoint if a slight undershoot is built into the servo. In its basic form, a PI servo is extremely easy to implement:

$$V = K(\text{ERROR}), \text{ and} \\ \text{ERROR} = \text{ERROR} + (|P_a - P_d|)$$

It probably would be better not to let the error accumulate indefinitely. The length of time should be a matter of empirical determination. The advantage digital control has over analog is that optimal control is possible; you do not need to follow in traditional lockstep with the classical servo equations.

Potential Uses. When I designed the robot cart, I had in mind a low-cost, integrated robotic system that would make use of an inexpensive robot, such as Microbot's Minimover. Possible configurations are shown in photos 8a and 8b. The robot could serve as a platform moving between fixed-robot work stations or, with suitable control wiring, a robot could be carried from station to station.

The latter application would provide a particularly inexpensive solution for low-resolution tasks such as picking up printed circuit boards and carrying them from place to place. Robots would not need to be placed at each work station, and the operation could be run by an Apple computer. □



Photos 8a and 8b. Two useful operations might be carrying the work to the robot (photo 8a) or carrying the robot to the work (photo 8b). Featured robot arms are the Microbot TeachMover (photo 8a), and Tomy's Armatron (photo 8b).

was adequate. It did not overshoot since there was sufficient mechanical damping, and therefore did not need velocity feedback as a damping term. Since power was adequate (at pay-

loads greater than 5 pounds) to move the cart incrementally at the slowest speed without overshooting, I did not need to implement an integral function.

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Hail Automation, Comp Arm	303/371-5868	\$ 90,000						✓								✓				
Hirata, AR300 Arm Base	317/846-8859	\$ 20,000	4.5	0.002				✓		21.6"	4"	270°				✓				
Hirata, Hi CNC	317/846-8859	\$ 9,000	110	0.002		✓				7.9"		7.9"				✓				
Hitachi, Assembly Robot 25	201/825-8000		4.4	0.002	59	✓	✓									✓				C
Hitachi America, "Mr. Aros" JP/SP	201/825-8000		11	0.04	0.1-0.7	✓				32"/40"	20"/44"	60°	± 100	- 50 to + 50	—	✓				C
Hitachi America, Process Robot	201/825-8000		22.2	0.008	39.4	✓	✓	✓		38"	46"	300°	+ 85 - 95	± 185		✓				C
Hitachi America, Spray Painting Robot 6V/6H	201/825-8000		11	0.08	68.9	✓	✓	✓		123"/52"	52"/123"	150°/110°	240	250	250	✓				C
Hodges Robotics, H35	517/323-7427	\$ 45,000	35	0.005	120		✓			48"	72"	360°	180	180	360	✓				C, P
IBM, 7535	800/327-0166	\$ 28,500	13.2	0.002				✓		25.6"	3"	200°			360	✓				P
IBM, RS1	800/327-0166	\$100,000	5	0.008	5	✓				58"	17"	18"	180	270	270	✓				
Ikegai America, FX-RBT	312/397-3970	\$ 39,000	11/22	0.02												✓				
Industrial Automates, Industrial Automate	414/327-5656	\$ 13,500	10	0.015	30		✓			24"	7"	120°	180			✓	✓		P	
Intarm, 100-S	513/294-0834		35	0.015	100		✓			14"	18.37"	320°		300		✓				
Intarm, 200	513/294-0834		50	0.04	250		✓									✓				
International Robomation, IRI-M50	714/438-4424	\$ 9,800	50	0.04				✓		80"	80"	540°	240	—	720		✓			P
I.S.I. Manufacturing, Modular Robotics	313/294-9500	\$ 75,000	150	0.005	90											✓	✓	✓		
C. Itoh & Co, Taiyo Toffky-2300	313/352-6570	\$ 67,000	22	0.008		✓				33.9"	7.9"	29.5"				✓				
C. Itoh & Co, Nachi Uniman 8600 AK	313/352-6570	\$110,000	75	0.04				✓		75.5"	84.4"	270°				✓				
KUKA Weld Systems & Robot Corp, IR 260/500	313/478-7850	\$130,000		0.04				✓		19.7'		8.2'				✓				
KUKA Weld Systems & Weld Corp, IR 601/60	313/478-7850	\$100,000	220	0.04				✓				360°				✓				
Lloyd Tool & Mfg Corp, Joblot 10	313/742-1820	\$ 90,000	155	0.010		✓				110"	69.2"	300°				✓				
Lamson, Robopal	315/432-5467	\$ 40,000	100	0.125												✓				
Lynch Machinery, E-Z Handler	317/643-6671	\$ 70,000	300 to 1000	variable	20											✓				
Mack Corporation, B-A-S-E Robot, Series II	602/526-1120	\$13,000/ \$18,000	5	0.010	10	✓				6"	8"	10"	180, 90	180, 90	180, 90		✓		P	
Manca, Fibro Manca*	201/767-7227	\$15,000/ \$200,000		0.003		✓	✓			49"	360°					✓	✓		✓	
Microbot, Alpha	415/968-8911	\$ 7,500	1.5	0.020	20			✓		18"	26"	330°	± 90		± 180	✓			P	
Microbot, MiniMover 5	415/968-8911	\$ 1,700	1	0.03	6			✓		17.5"	25.6"	180°	± 90		± 180	✓			P	
Mobot, Mobot	619/275-4300	\$ 45,000/ \$ 60,000	600/1000	0.03	36	✓				N/A	15'	15'x100"	360	360	360	✓	✓		P	
Mobot, Mobot Columnar	619/275-4300	\$ 45,000	1000	0.03	18		✓			3'	20'	0	0	270	0	✓	✓		P	P
Mobot, Mobot Vertical Bridge	619/275-4300	\$ 60,000	1000	0.03	18		✓			3'	20'	100'	0	270	0	✓	✓		P	P

* modular

These tables are reproduced from the Stock Drive Products Data Book, Volume 2 available at \$7.95 from: Educational Products, P.O.Box 606, Mineola, New York 11501.

This material is authored by Bernard Roth, a professor in the Design Division of the Mechanical Engineering Department at Stanford University in Stanford, California.

A PORTABLE ROBOT TASK ANALYZER

Russ Adams
3008 Mosby Street
Alexandria, Virginia 22305

Purchasing an industrial robot isn't like hiring an extra employee. Robots are large, heavy, expensive things, and you can't just fire them if they fail to do their jobs. You need to know in advance if a robot can perform the job effectively.

Each robot is unique, with unique mechanical response characteristics that limit the type of work it can perform. As a result, a particular robot may be incapable of performing a specific job.

The job may require a robot manipulator to move with a velocity greater than its link actuators are capable of achieving. The job may require lifting an article with a weight that will overload the link actuators. Even if the manipulator can physically perform the job, the robot still may be incapable of the necessary motions due to controller limitations. The controller may be unable to store the entire required sequence of motions or perform them with sufficient speed.

These problems encountered when adapting a robot to a specific job make it desirable to test the robot before installation. If a robot is to be used for spray painting on an assembly line, for example, you need to be sure it can perform the job before you purchase and install it. Without such pretesting, you run the risk of purchasing and installing a robot incapable of doing the job because of

physical limitations in its actuators, controllers, or power supply.

One solution to the pretesting problem is taking the article to be spray painted to the robot manufacturer. You can test the robot to determine if any physical limitations will prevent proper painting.

What if the article to be spray painted is too large to be transported to the robot manufacturer? The test is not possible. Even if the article is small enough to be transported, you

may be unable to duplicate the manufacturing environment. The article, for example, may normally move along an unusual path on an automated assembly line.

So why not bring Mohammed to the mountain? That's the solution posed in patent number 4,360,886, issued to Evans Kostas, Gerald Crum, and Jerome Walker on November 23, 1982. The patent is owned by the Nordson Corporation. This patent describes a method and apparatus for

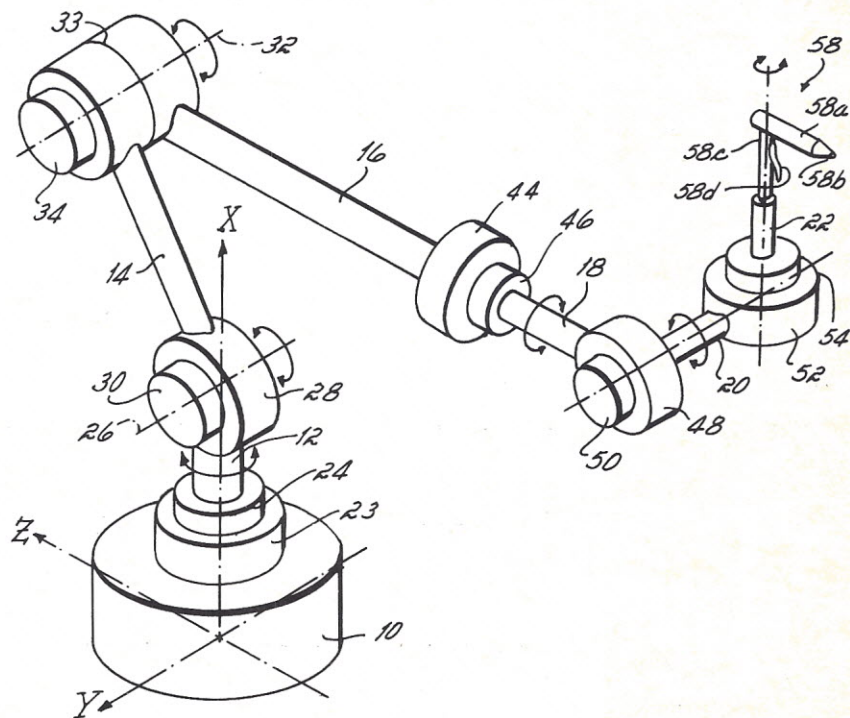


Figure 1. A typical industrial robot has massive linkages.

The illustrations in Patent Probe are reproductions of diagrams in the original patent documents.

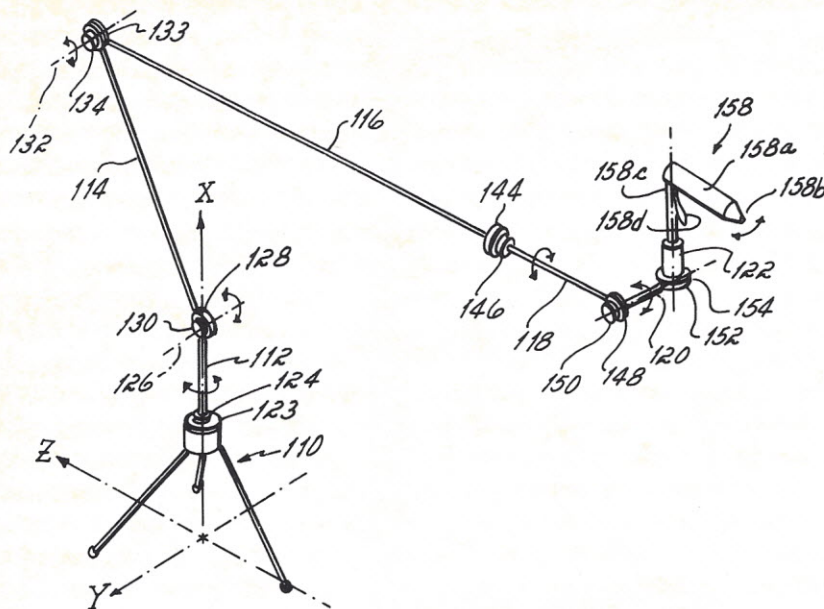


Figure 2. The proposed lightweight, hand manipulable robot simulator is constructed with the same dimensions as the industrial robot, but with much lighter linkages.

analyzing the feasibility of performing a sequence of motions with a robot.

The invention proposes providing a portable, relatively lightweight, manually manipulated robot simula-

tor at the manufacturing site. The simulator consists of plural linkages with degrees of freedom that simulate those of the robot under consideration.

Each arm linkage contains a posi-

tion sensor. A wide band signal recorder records the signals from each sensor as the linkages are manually manipulated. Other sensors generate signals which simulate other operations, such as activating a spray gun or closing a gripper.

The robot being considered can be driven by the recorded sensor information. As the sensor signals drive the robot through the motions required to perform the job, the sensors on the robot generate actual linkage position signals. These signals are also recorded by a wide band recorder.

After the test job is completed, the records for both the actual and simulated job performance are analyzed. The automated analysis produces error signals, which correlate to how well the robot performed the job. A technician displays the error signals for further analysis, to determine if the robot can successfully perform the job.

If the display shows no significant position or velocity errors, the robot is clearly able to perform the job. If

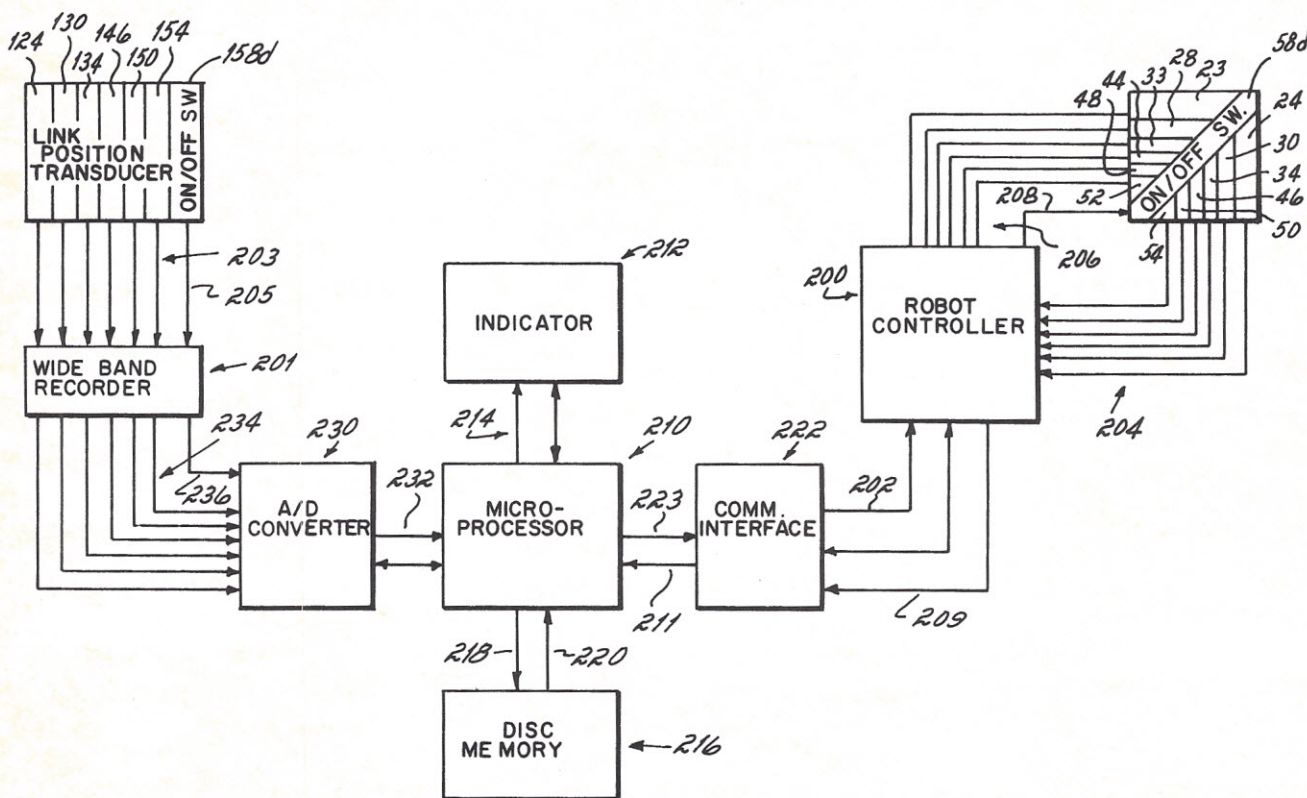


Figure 3. This block diagram describes how data from the wide band recorder is used to determine the feasibility of using the robot to perform a job.

errors occur at points in the sequence of operations that would not affect the successful completion of the job, the errors can be ignored. The judgment of what "successful completion" means is up to the technician analyzing the display.

Experience may demonstrate, for example, that a position error of $\frac{1}{2}$ inch can be tolerated when the robot applies rust inhibitor to an automobile. The same position error is unacceptable if the robot is applying decorative pinstripes. Similarly, velocity errors that result in variations in paint thickness may be acceptable when the robot paints tractor engines, but would not be acceptable if it was applying reflective coatings to mirrors.

The patent describes a typical industrial robot as having a base that rests on the factory floor. Extending from this base are plural, series connected, articulated linkages. These plural linkages generally provide the robot with six degrees of movement and usually are massive. Each link-

age can be 1 to 4 feet long and weigh up to 400 pounds.

Industrial robots are operated by programmed controllers. The controller program contains a series of linkage positions required to perform a given job. The controller retrieves these stored linkage positions in sequence and compares the actual position of the robot's linkages to their desired positions.

Based on this comparison, error signals are generated. These error signals are then used to operate actuators, which move the linkages until the error signals for each linkage position are zero. "Zeroing out" the error implies that the desired position is attained.

The proposed robot simulator is supported by a tripod base. Extending from the base is a vertical linkage, which is rotatably connected to the base. A position sensor in the base provides a signal that indicates the angular position of the linkage with respect to the stationary base.

A second linkage is pivotally con-

nected to the upper end of the vertical linkage. A second sensor provided at the joint produces a signal proportional to the relative angular position between the two linkages. Three other linkages are each serially connected with sensors positioned at each joint. A manipulator or tool is mounted to the end of the last linkage.

The lengths of each linkage in the robot simulator are identical to those in the prospective industrial robot. Each simulator linkage, however, weighs a fraction of the weight of its respective real linkage counterparts.

The simulator is moved manually through the steps necessary to perform the job. As this movement proceeds, the various sensor signals are recorded. If a robot containing M linkages executes N position commands per linkage per second, then the recorder must record at least $N(M+1)$ commands per second.

After the simulation is completed, the recorded sensor information is transported to the robot manufac-

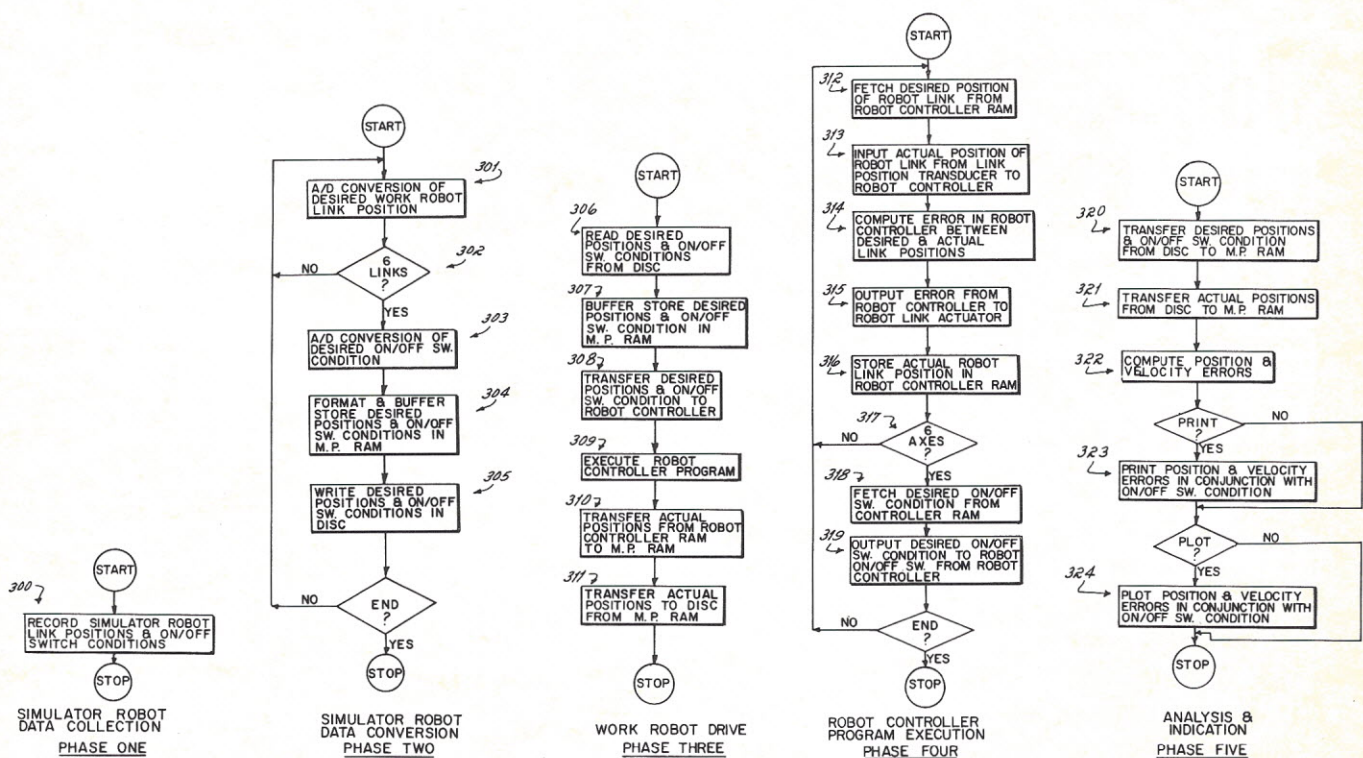


Figure 4. These flow diagrams show the steps in the five phases of the analysis method.

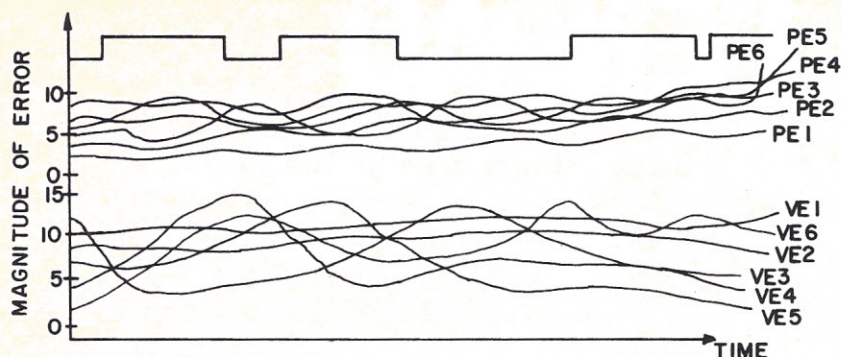


Figure 5. A typical graph produced by the analysis shows the error between simulated and actual operation.

ture. The information is played back through an analog to digital converter, which converts the analog sensor signals into digital equivalents.

The digital signals are processed by a microcomputer that "groups" signals from the plural sensors with respect to time. These grouped signals are stored on disk for retrieval during job playback and analysis.

The stored sensor values are retrieved from disk and transmitted to the robot controller via a com-

munications interface. The values cause the controller to operate the robot—moving linkages or operating the arm's effector. As the robot duplicates the job motions, the output of the robot's sensors is transmitted back through the communications interface to the microcomputer. These signals are also processed by the microcomputer and stored on disk for retrieval during the analysis phase.

Once the job operation is com-

pleted, analysis can begin. The groups of stored sensor values are retrieved and used to produce graphs. These graphs show how closely the desired operation was mirrored during playback. Based on these graphs, a decision can be made regarding the feasibility of using a given robot to perform the job.

This patent is an improvement of patent number 4,305,028, titled "System for Evaluating the Capability of a Work-Performing Robot to Reproduce a Programmed Series of Motions."

Copies of both patents are available from the U.S. Patent and Trademark Office for \$1.00 each. Send orders for patents with payment to: Commissioner of Patents and Trademarks, Washington, DC 20231. □

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THE PENPAD

HANDWRITTEN INPUT FOR COMPUTERS

Kenniston W. Lord, Jr.
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Winchendon, Massachusetts 01475

During the past two decades, the simple entry of data has remained a complicated problem. Some people who might logically have used the computer have resisted because simple devices for entering data were not available. The problem is magnified with the advent of personal computers and their use in business and industry. The inability to type has been identified as one major reason people resist using a microcomputer. Microcomputers, however, are becoming a way of life and a key to increased productivity. Many businesses depend upon them to remain competitive. It is necessary for people who cannot type and for executives (according to a recent *Time* magazine article) to overcome their fear of typing.

Penpad, by Pencept, Inc., of Waltham, Massachusetts, is a graphics tablet, algorithmic interface, pen/stylus package which permits you to enter handwritten data and command directives to a computer (not only microcomputers, but also larger systems). The Penpad interprets handwriting via a process called "dynamic character recognition" (DCR). All that is needed to communicate with the computer is paper, pen, and Pencept's digitizing tablet.

All you need to know to use the device for data entry is how to block

print the English alphabet and Arabic numerals. The algorithms built into the unit can even understand sloppy printing. Figure 1 shows sample characters that the Penpad can interpret. The Penpad system recognizes a fairly wide variation in print style.

Writing Tablet. A square graphics tablet, 15½ inches to a side, provides the surface for mounting a paper form. The tablet is divided into two sections: a data entry area and a command area (where hardware or software specific commands may be placed). Figure 2 illustrates the tablet layout. Standard paper size is 8½ × 11 inches. The paper is printed with a grid, which coincides with the grid

mounted in the graphics tablet. Either locally produced forms or forms prepared by Pencept may be used. Figure 3 shows a typical Pencept-supplied form. A calibration procedure aligns the form and tablet. While this tablet size is common, graphics tablets of different sizes are available.

To use Penpad, place a form on the tablet surface and follow the alignment procedure. From this point the unit takes over, and you simply write on the form. The interface unit transmits the characters to the main computer. Tablet form grids are defined and software commands identified to the computer. All data captured is ASCII data, which any program

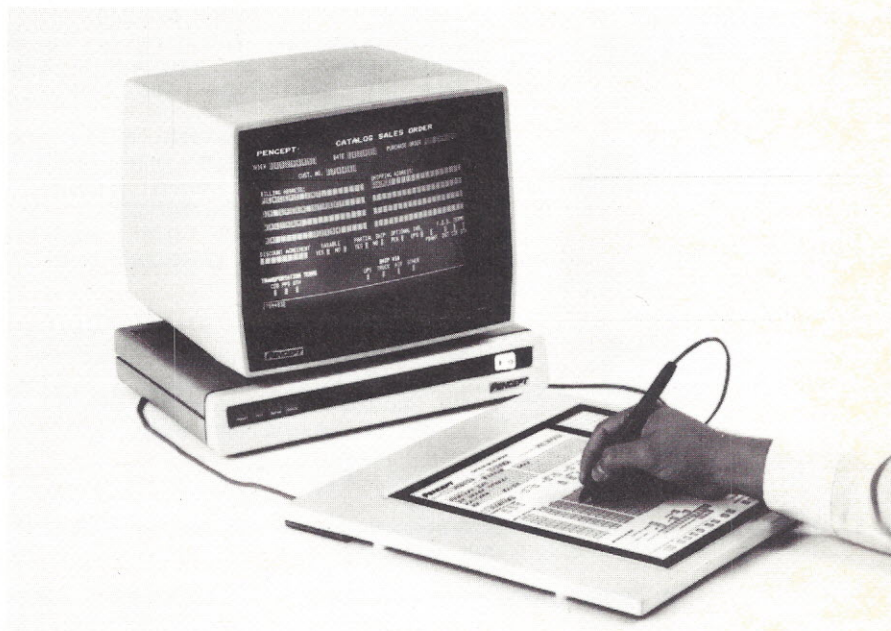


Photo 1. The Pencept Penpad uses handwriting as the primary method of data entry. Penpad consists of a writing tablet and an electronically controlled ball-point pen. It recognizes all letters of the alphabet, numbers, and 15 other characters in a wide variety of styles.

About the Author

The author is a consultant and writer in the data processing industry. He is the author of several books about microcomputers and has published numerous articles in the information processing trade press.

established to read an ASCII file or communication can process.

The writing is performed by a stylus, which contains a standard ball-point pen cartridge and is attached to the controller. Direction sensing is built into the stylus. The interface accepts block characters A through Z and 0 through 9, and 15 other characters. When the character is written, you can verify it simply by looking at the computer's display screen. Uninterpretable characters appear as question marks in the appropriate positions. Correction is as simple as rewriting the character. To improve the input process you can make data editing a function of the controller's entry interpretation. The grid boxes can be defined to accept data, reject data, move a loaded string, or accept only certain valid characters.

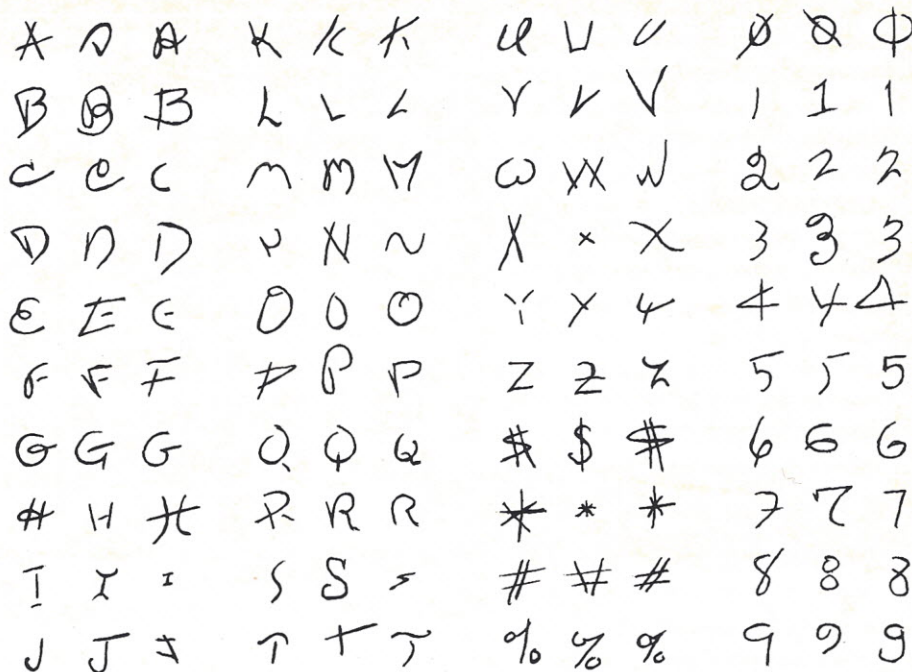


Figure 1. Examples of the large variations in handwriting styles the Pencept Penpad can accept. Figures courtesy of Pencept, Inc.

Controller. The controller is quite small, 3 inches by 14 inches by 11 inches. It is typically placed beneath the system's monitor. Any host computer with a standard asynchronous RS-232C interface can use the Penpad. The Penpad controller interface contains its own memory; no additional memory is needed by the host computer, except the memory needed to operate the software that uses Penpad data.

Penpad has three input modes:

- **Character coordinate mode.** As each character is hand printed, it is transmitted to the computer with its tablet row and column position. This mode allows the software to take maximum advantage of the input that has been written on the graphics tablet, as the specific location of the data upon the form can be determined. It also logically aligns boxes on the paper forms to memory boxes located in arrays, or positions of memory. The actual writing process, dynamic character recognition (DCR), is discussed below.
- **Keyboard compatible mode.** As each character is entered, it is transmitted to the computer as the

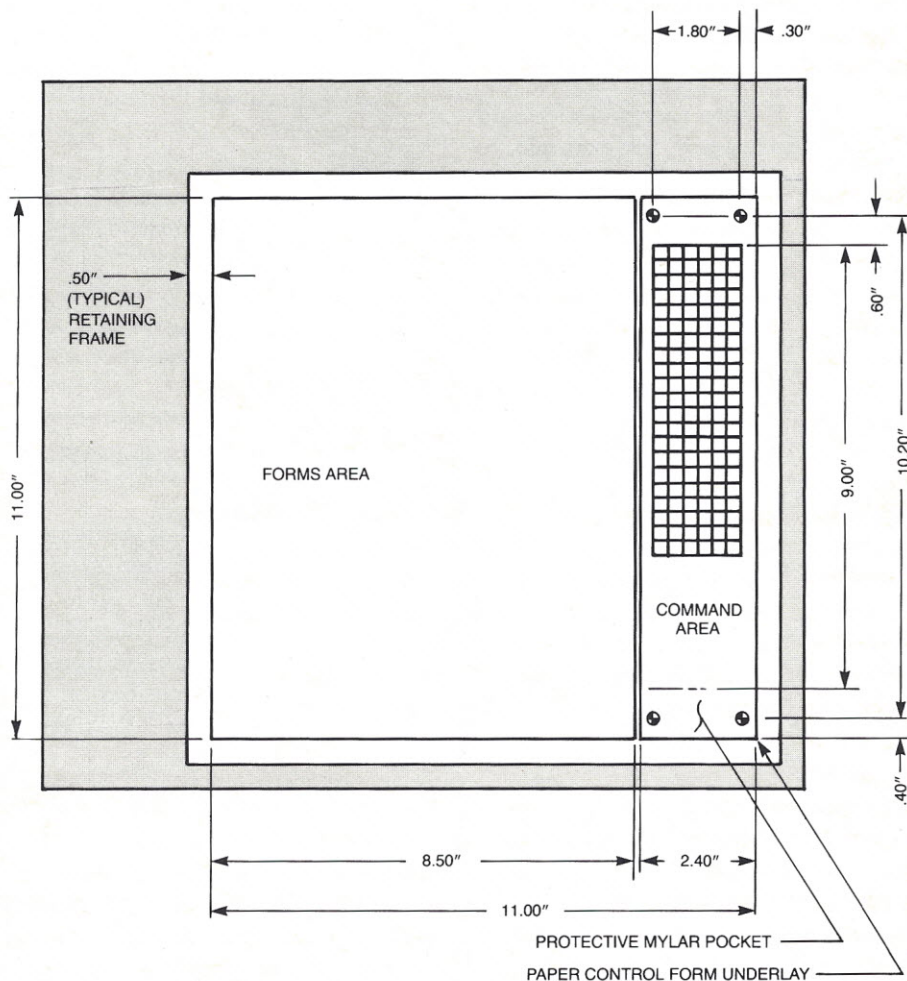


Figure 2. A typical tablet layout. The tablet area is divided into a data entry area and a command area. The special character is transmitted when a checkmark is placed in a command area.

- **Graphics input mode.** Penpad contains a standard graphics tablet capability, which lets Penpad function as a digitizer. This facility permits the mixture of graphics and lettered input, allowing applications that combine both text and graphics.

DCR is the state of the art in computerized pattern recognition. Before it was developed, computers could recognize a pattern that had been placed within the confines of known boundaries. DCR electronically simulates the hand movements used to form characters and is not constrained by the specific size of the character. Pattern recognition would require the letter B, for example, to be positioned at one specific set of location coordinates on the graphics tablet. That is also required for character entry on preprinted forms in the character coordinate mode. It's somewhat different in the keyboard compatible mode, however, as a 6-inch letter B will be interpreted correctly and will appear in the next available position on the entry line.

The algorithms built into Penpad are extensive, incorporating not only the characteristics of those who can print nearly perfect letters, but also the characteristics of those who tend to be somewhat sloppy. To provide this level of sophistication, some considerable capability has had to be built into the system to allow for individual, cultural, and academic factors. The human tendency, for example, to form similar characters when

Figure 3. A typical form supplied by Pencept. You can also create your own custom forms.

How DCR Works. The process of printing is imprecise. When printing, a person moves a pen in diverse directions at varying speeds. The pen point is moved back and forth, up and down, and is lifted from or dropped to the paper. Each of these actions forms the basis of a pen stroke. Combine a pen, a high-

Penpad takes a raw impression, refines it, performs pattern comparisons, and selects the closest match. Handwriting the character first produces a very rough image. To clean up the rough image, a pre-processor straightens lines, removes extraneous marks and shapes the letter to conform to one or more of the images incorporated into the con-

troller's algorithms.

In the character coordinate mode, and in some instances in the keyboard compatible mode, the character is written in a precise place on the paper. Because the location is a definable size, and since the bulk of the character is formed at that location, shaping the character is easily performed.

A second space limitation also exists. The hand strokes used to form the letter F are precisely the same as those used for forming the letter I and an equal sign. It becomes the letter F because of the close proximity of the lines. If, however, there is a spacial separation between the two, there will be a problem in the keyboard compatible mode, as what was supposed to be a single character shows up as two characters. That problem also extends to the letter B, which could be interpreted as the number 13 and would be printed in two adjacent boxes in the character coordinate mode.

DCR has two sets of rules: generative and perceptual. Generative rules detail the character-forming movements. Movement is sensed by the pen point, detected by the stylus, and transmitted to the controller. All the logically possible ways to form a handwritten letter have been defined to the unit. Those methods are then compared to the handwritten letter.

The rules will be defeated periodically, for only a finite set of letter formations has been included. The perceptual rules define how the entered shapes are compared to previous shapes within the system. These methods provide nearly instantaneous recognition, according to Pencept. Pencept advises that if the writer prints letters that are so sloppy that another person would have difficulty recognizing them, the computer cannot be expected to do much better.

While hand print recognition technology is relatively new, it has overcome a major obstacle that confronts

potential computer users. It is no longer necessary to type or to become intimately familiar with the computer keyboard. And, best of all, training is not an extra expense. The fundamental training necessary to effectively use the Penpad was completed when the user learned to print. Training to use the Penpad is minimal: turn on the computer, load a disk, load a form, pick up the pen, and print.

Hand print recognition technology bridges the gap between keyboard and potential voice-actuated entry of data to the computer. It is a current technology. Only concern for the cost of the unit and a lack of imagination can delay its use. Once Penpad shows its stuff, these concerns will evaporate. □

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THE GET AWAY SPECIAL

PART II: FLIGHT PREPARATIONS

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Once your Get Away Special (GAS) experiment and associated hardware are ready to be assembled, NASA will provide you with the experiment mounting plate (EMP). This base is a $\frac{5}{8}$ inch thick aluminum disk that has a 22.687 inch diameter (for detailed specifications see figure 1). The weight of the standard GAS container, experiment mounting plate, the EMP mounting screws, and all hardware regularly supplied by NASA is not charged to the experimenter's weight allowance. The EMP is the only part of the actual GAS container that NASA supplies to the experimenter prior to the launch preparation. This is because it is the only solid surface mount for the equipment; no other inset connections can be incorporated into the GAS container.

The bottom and sides of the GAS container are constructed of aluminum and are thermally insulated. The top of the container may be insulated, or not, depending on the specific experiment. An experiment with an opening lid or a window may not require insulation on the top; however, this could produce thermal problems.

The EMP is always attached so that it faces out from the payload bay of the orbiter. Modifications to the EMP for such openings may be offered at additional costs and must be arranged through NASA. All connections to the Shuttle Orbiter, such as command links and venting, are

made through the NASA interface equipment plate. The bottom 3 inches of the GAS container are reserved for this interface equipment plate and related hardware. The space that this interface fills is not part of the total cubic feet that an experimenter purchases.

NASA has been able to utilize payload space constraints and place an experiment on the Shuttle with greater efficiency by standardizing the GAS container sizes as well as the EMP. The plate can also serve as a

thermal absorption or radiation surface and is compatible with both GAS container sizes. The interior surface of the EMP has an equidistant hole pattern that accepts from 10 to 32 UNF machine screws to a depth of 0.31 inch. Forty-five stainless steel, internally threaded inserts are available as mounting supports for the interior of the GAS experiment.

The proper disbursement of weight is one of the most critical factors in the design of a GAS experiment. The Shuttle loading, launch, and landing

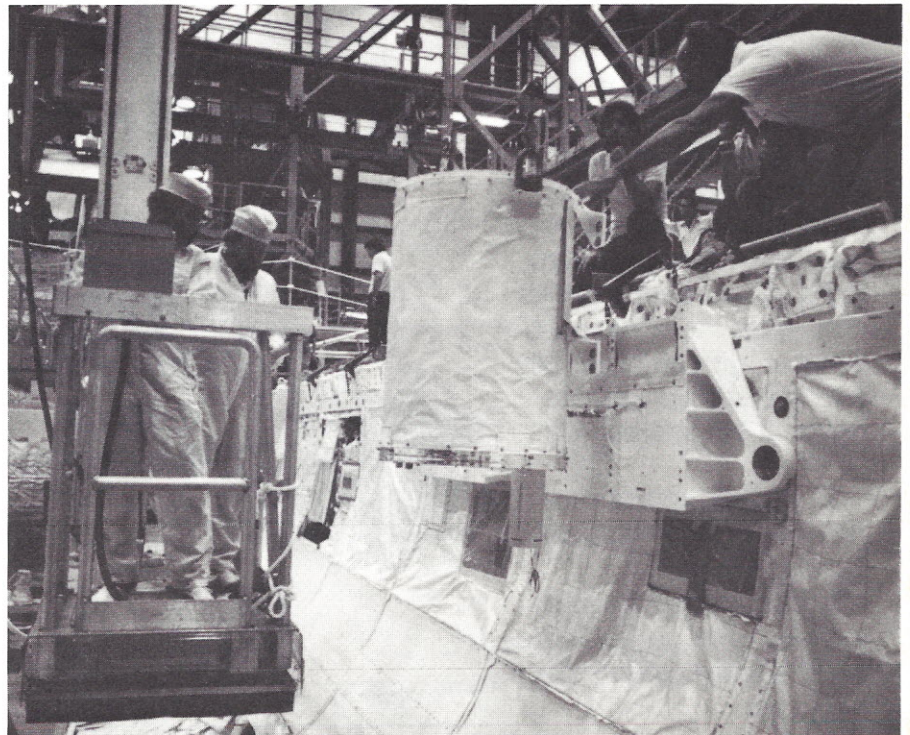


Photo 1. The GAS experiment is loaded into the Shuttle's cargo bay and remains perpendicular to the Shuttle throughout the mission.

GET AWAY SPECIAL SMALL SELF-CONTAINED PAYLOADS

STANDARD EXPERIMENT MOUNTING PLATE

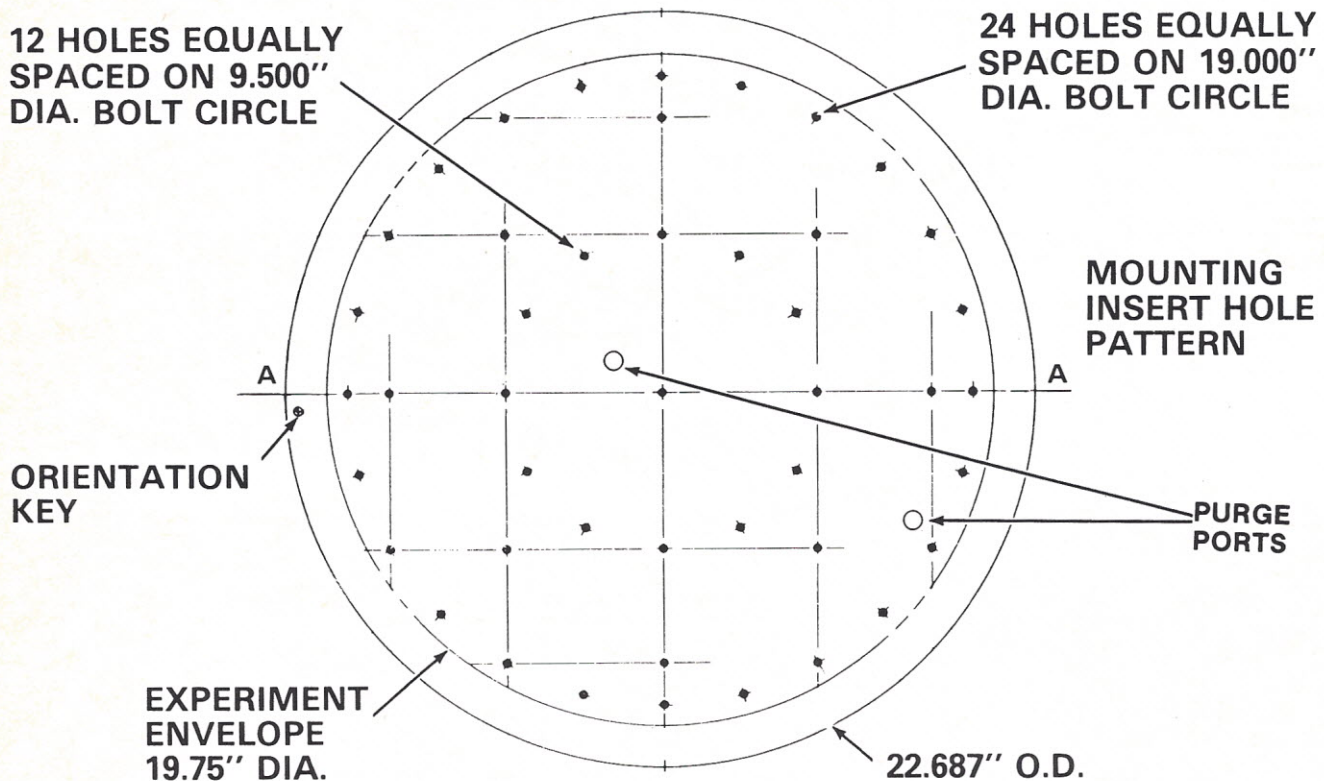


Figure 1. A detailed look at the dimensions of the experiment mounting plate (EMP).

all produce severe stress on the experimental structure within the GAS container. One of the ways to eliminate the problems of stress is to place the heaviest pieces of hardware directly on the EMP. To support the opposing end of the GAS experiment structure, it is necessary to insert suitably resilient, non-outgassing material capable of withstanding temperature extremes. NASA has termed these lateral supports. These minor and inexpensive attachments ensure an easier flight to and from low Earth orbit by bracing, not inseting, against the wall of the GAS container.

Since the GAS must operate independently of the Shuttle Orbiter, the designer must provide electrical power, heating, data handling and so on within the GAS container. The user is not able to draw upon any

Shuttle services beyond a hand-held command decoder unit, operated by an astronaut, and a pressure regulator system. In order to carry a variety of experiments, the GAS container has been designed to provide for internal pressure which can be varied from near vacuum to 1 atmosphere. Some of the various configurations of this pressure vessel include evacuation (or depressurization) prior to launch; evacuation during launch and repressurization during reentry; the maintaining of 1 atmosphere pressure at all times; or evacuation and repressurization during orbit as provided by the experimenter.

Each GAS payload is lowered into its container at Kennedy Space Center, and subsequently is attached to the NASA interface plate (photo 1). All lateral supports are checked and reset if necessary. The last stage in

this preparatory mode is sealing the container. The EMP, facing out from the payload bay, is battened down and checked for leakage. Then, a 1 inch insulation material is placed on the container, as required by NASA, unless it obstructs a possible window or lid.

Once the Shuttle has been prepared for launch, the Orbiter is towed to the vehicle assembly building (VAB) where it will eventually be hoisted onto the already vertical external tank and solid rocket boosters (SRBs). The GAS experiment remains perpendicular to the Shuttle's major axis throughout the mission. Great care should be taken in experiment design to ensure that systems that are sensitive to ground orientations, such as wet cell batteries, are properly oriented. Requests for special orientation requirements and handling of

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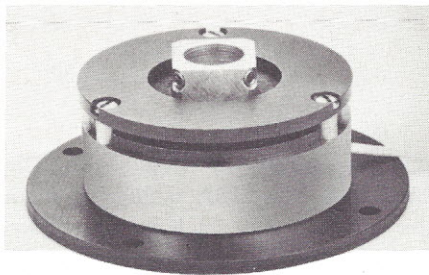
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CIRCLE 8

LINEAR VS. EXPONENTIATING SYSTEM IN PRODUCTION

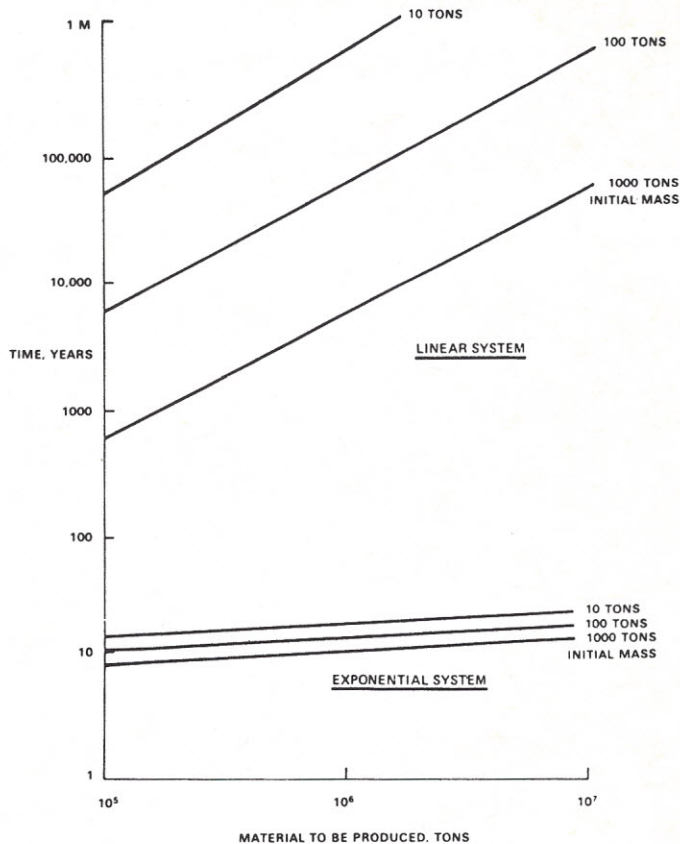


Figure 2. This graph shows the production differences between exponential and linear production systems. The exponential systems produce much more material in less time than the traditional linear systems.

GAS payloads should be placed with NASA prior to the actual installation.

Talking Payloads? Once your experiment is activated, the robotic GAS operates within the quiet confines of its container. In the future, however, it will be possible to build payloads that sing, give instructions, and perhaps even converse with the astronauts. If voice synthesis circuits are connected inside the control panel of the Shuttle, astronauts will have a much more efficient system for monitoring and controlling the Shuttle. Instead of depending totally on visual screens and monitors, the astronauts will notice problems quicker and fly the Shuttle with less chance of error, using these monitors' words and directions. If voice synthesis circuits are connected inside the crew quarters of the Shuttle, the astronauts might be awakened by the

words, "Wake up. It's time to turn off GAS experiment number 2." In fact, the development of synthesized sound will present many new options for the roboticist as well as for the potential GAS user.

Several companies are already marketing voice synthesizers. Since a message can be quickly understood when spoken, rather than just implied by alarms and buzzers, voice synthesizing machines will be used in the future as components for many robotic and mechanical systems.

The Future of Robotics in Space. Voice synthesis is just the beginning of a more symbiotic relationship between people and machines in space.

Inevitably, we will see more applications of robotics technology as an extension of human capabilities, rather than a replacement for unique human qualities. Voice synthesis

technology, for example, will eliminate the need for an astronaut to monitor an overwhelming array of dials and indicators during an exceedingly complicated sequence of operations. The astronaut will be *told* which dials are reaching critical points and which operations require attention.

Further applications of robotics technology, although somewhat beyond the average GAS payload, will build upon this early robotics experience. Many space manufacturing schemes require placing automated machinery and equipment in orbit, on the Moon, or on an asteroid. This equipment will extract the basic raw materials from which further commodities can be made. This approach to manufacturing can be described as a linear system.

On the other hand, an exponential system consists of a system which self-replicates, eliminating the need for the placement of massive processing facilities in space. Robotics technology will make it practical for

machines to be placed on the Moon or on an asteroid, both of which use available natural resources to reproduce. A rapidly increasing number of identical self-replicating machines could comprise factories that would then produce the finished product.

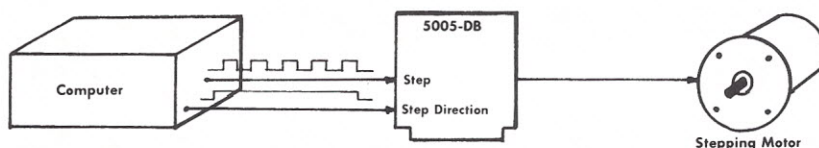
The conceptual framework for such automata that mimic biological systems was established by Von Neumann. NASA, at the recommendation of a special study group of its Advisory Council, has investigated the subject thoroughly as part of a summer study at NASA Ames Research Center in Mountain View, California.

The difference in output between linear and exponentiating systems could be very dramatic. If a linear-based manufacturing operation produces X tons of output per year, then in 20 years, 20X tons of total output are produced. In the case of an exponentiating system with machines capable of reproducing themselves at only 1 percent of the product rate of the linear machine, a 1 year per

generation time would create 2^{20} machines in 20 years—over a million machines, which by then would have produced at the reduced 1 percent production rate over 10,000X tons of output.

Such dramatic order of magnitude differences make feasible the potential financing of large-scale space processing schemes with relatively small amounts of capital invested in robotics technology, rather than in massive linear-based space habitation schemes. Since most of any space venture's cost comes from transportation, minimizing the amount of initial mass to be carried from the gravity well of Earth minimizes the total investment for a particular space scheme. Exponentiating systems reduce initial mass requirements far beyond the potential initial investment required to develop such exponentiating systems (see figure 3).

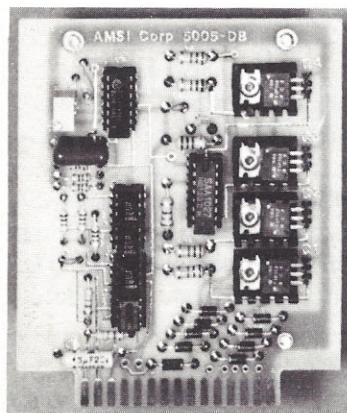
Of course, the ideal self-replicating automata are some way in the future. Large sums of research and develop-



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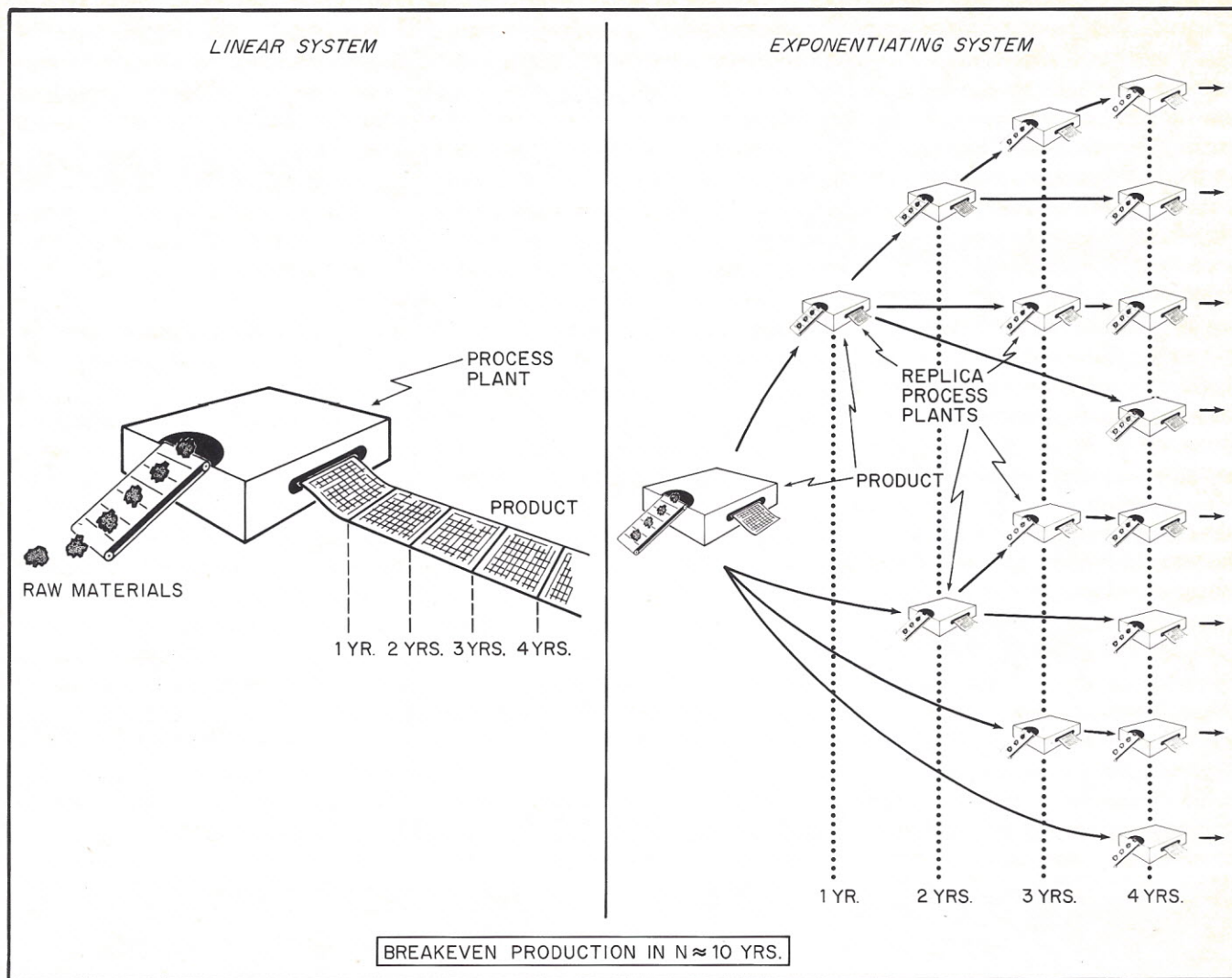


Figure 3. Exponential systems use some of their time and energy to build more production machines. Besides being able to produce more material, the production rates of exponential systems are not severely hampered when one or two machines are damaged. The linear system loses an irreplaceable amount of production; the exponential system can recover from the loss.

ment money are necessary to develop the concept, but the principle of exponentiating automata can be applied in hybrid fashion with human interaction. A similar effect to a complete automated system may be achieved by having the bulk of materials manufactured by the machine, with a human operator adding control and several key trace components such as integrated circuits or specialized chips.

Such systems for space use would come as the end product of a long process of developing automata technology, robotics, and machine intelligence, which has started with the robot-based Get Away Special. And

as a spin-off, the tools and techniques developed for this space application will have tremendous value here on Earth.

Don't forget, the whole process begins here on Earth with an idea, a concept to be tested in space. Getting from concept to reality is no mean feat, especially since there are no self-replicating idea machines available at the present time to help the potential GAS user. Help is available, however, in practically all aspects of a GAS payload project.

GAS R&D Services. The Get Away Specials, although economical and relatively easy to place on the Shut-

tle, pose various structural problems for those unacquainted with aeronautics and astronautics technologies. Testing, inspection, and consulting services are valuable for a nontechnical builder, because they reduce retrofitting expenses and help design a GAS container without wasted time and frustration. NASA is able to help in the design of educational projects, but is prohibited from consulting on corporate or individual ventures that have possible commercial applications. Noneducational experimenters must turn to engineering service organizations for their consulting needs.

There are many such service orga-

nizations, but most will do business only with large establishments with large budgets. The evolution of the Get Away Special has produced some service corporations which are eager to work with GAS experimenters because they have had previous experience with space payloads or have successfully launched GAS containers.

Delta Vee, Inc., a nonprofit space research corporation based in California, offers a GAS consulting package. With its past experience in financing various government space projects, Delta Vee has experience interfacing between the public and NASA in a direct funding and technical mode. Delta Vee was organized in 1980 and currently subsidizes space projects such as the Viking Lander on Mars, the International Halley Watch, and the Search for Extraterrestrial Intelligence. Delta Vee also consults on many small space contracts, including GAS experiments. Mostly made up of aeronautical and astronautical engineers, Delta Vee consults to a wide variety of customers with special needs.

Once you have an idea for a GAS experiment, your first step is to contact NASA or an aerospace corporation about a space in the payload bay of the Shuttle Orbiter. Currently, to reserve such a place requires a nonrefundable deposit of \$500. Although there are as many as 480 reservations, very few projects are actually ready to fly.

Once a reservation is made, the most efficient way to review a procedure is to consult with outside engineering help. One of the areas in which consulting proves to be particularly important is in hardware design. The space environment poses problems for many of the common machines and materials used in terrestrial living. When in doubt, get some professional consulting.

A Get Away Special is not only a unique opportunity to experiment in space, but it can be a substantial investment. Space is a very harsh and different environment, so harsh that terrestrial thinking cannot always be applied to structural design and the choice of specific equipment. Con-

sultants often can troubleshoot unconventional problems that may develop. Consultants know contacts and referrals who specialize in very specific areas. There are many engineering consultants who have worked on other Get Away Specials and can help designers from the beginning blueprints to the final testing.

Testing a Get Away Special is crucial. Delta Vee and other aerospace companies can obtain the type of equipment necessary to test a GAS experiment to the extremes.

There are other GAS considerations besides engineering. The GAS experiment has the potential of making a large-scale discovery. There are ways of protecting an idea, and many experimenters have done so. There are public relations services in the aerospace industry, which offer an attractive way of publicizing a GAS experiment and its creators. At the completion of a Get Away Special, an experimenter may wish to assemble a paper with the experiment's results in a conclusive report.

Altogether, there is much to be experienced and much to be learned through the challenge of launching a Get Away Special. GAS experimenters can participate throughout the many phases involved with loading, launching, and activating the Get Away Special. NASA's greatest ambition was to involve the public with the space program. As a result of the program, NASA involved not only the public, but robots too!

Resource Information. Further information is available from NASA by writing to:

The Get Away Special Program
Technical Liaison Office/Code 741
Goddard Space Flight Center
Greenbelt, MD

For suggestions and a place to start when pricing materials and components, here is a partial list of materials compiled by NASA. This list should not be perceived as presenting the top of the line or necessarily the most acceptable

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choices for your project. For quick response, you might telephone manufacturers listed in the *Electronic Engineers Master Catalogue*, published by the United Technical Publications, 645 Stewart Avenue, Garden City, NY 11530, or the *Electronic Buyers Guide*, published through the auspices of the Institute of Electronic and Electrical Engineers (IEEE).

Brochures from battery manufacturers are only partially helpful. We have found that an optimum battery choice can be achieved only by going to the manufacturers for a quote on your exact requirements. NASA does not permit the use of lithium-organic batteries on the Get Away Special due to their hazard potential. When nonhazardous lithium batteries become available, NASA will lift this

constraint. Silver-zinc batteries are a reasonable alternative for similar energy density. Silver-zinc batteries also have some potential for hazard, primarily due to the generation of hydrogen during discharge and oxygen during charge. Some of the precautions for limiting this hazard are listed below:

- Purchase batteries manufactured for low outgassing.
- Cycle the battery two or three times to drive out remaining hydrogen.
- Use a two-wire system, that is, float battery case.
- Shunt cells with diodes to minimize reverse current as cell becomes reversed.
- Employ active circuitry to cut power when low cell voltage is de-

tected. This prevents cell reversal.

- Use sealed batteries and/or a sealed case with over-pressure relief venting.
- Use materials for case, potting, and packing that are chemically compatible with the electrolyte.
- Use a thermal sensor to cut power if temperature rises above 80 degrees C.

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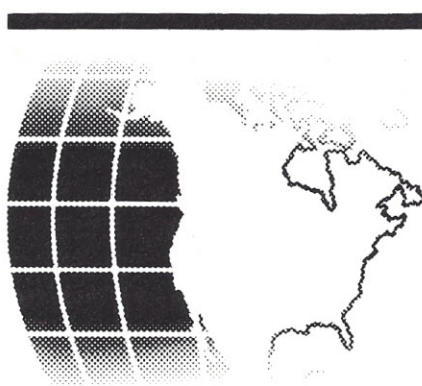
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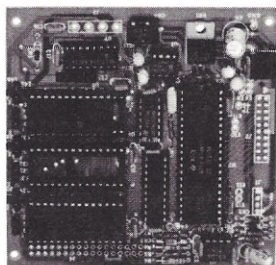
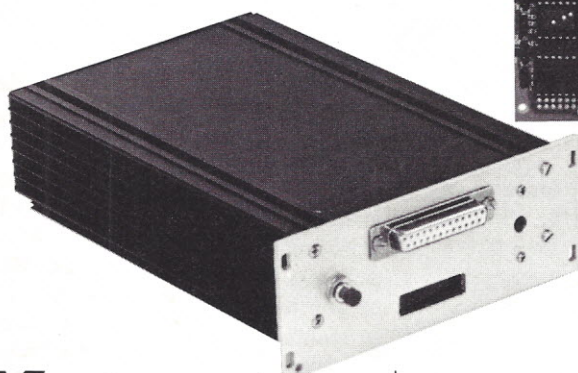
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New Products

Forth Development System



New Micros, Inc., has introduced the NMIX-0011 single-board computer. The dedicated Forth system is designed around Rockwell's R65F11 6502-based microcomputer, which contains the run-time portions of Forth in read-only memory. Adding an external terminal and power supply results in an operational microcomputer system. The NMIX-0011 provides 192 bytes of static RAM, 16 bidirectional, TTL-compatible I/O

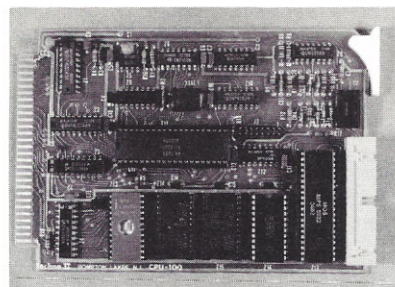
ports, one 8-bit port with latched input, two 16-bit programmable counter/timers with latches, one serial port, 10 interrupts; expansion to 16K bytes of external memory, 1 microsecond minimum instruction execution at 2MHz clock rate, and requires only a +5V power supply.

For more information, contact: New Micros, Inc., 2100 North Highway 360, Suite 1607, Grand Prairie, TX 75050. (214) 660-1106.

CIRCLE 34

High-Speed 6502 Board

The CPU-100 from Techno, Inc. is an STD-bus-compatible card with a 6502 processor, 8K on-board memory (RAM/ROM), 6522 VIA for two user-defined I/O ports, and one RS-232C interface. A 2K byte monitor and math pack are available. The monitor provides subroutines for terminal communications. The math pack includes multiplication, division, square root, and sigma determination algorithms.



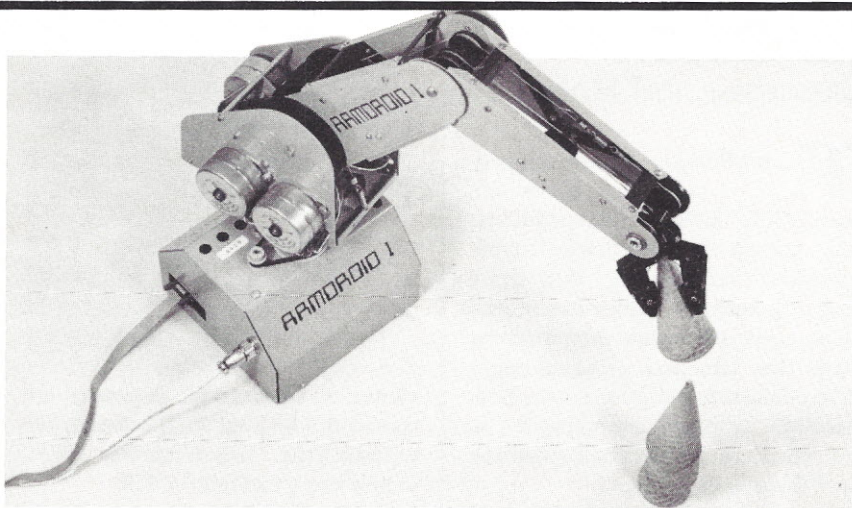
The CPU-100 is designed to function as the main processor in a multi-board system. A full 64K bytes of memory can be addressed. The list price is \$200.00. Contact: Techno, Inc., 14 Crandall Avenue, Pompton Lakes, NJ 07442. (201) 839-0740.

CIRCLE 35

Armdroid 1

The Armdroid 1 from Colne Robotics is an educational robot designed to be connected to various microprocessors. An on-board computer controls the five stepping motors that drive the arm. A simple interface card is required for each type of computer, such as the Apple II series, to which the Armdroid 1 is connected.

What separates the Armdroid 1 from other educational robot arms is its three-fingered gripper. The three-fingered gripper can capture circular or conical objects more easily than a two-fingered gripper. The accompanying photograph shows the Colne Armdroid 1 grasping its homophonic



namesake, the ice cream cone. This move would be difficult, if not impossible, with a two-fingered gripper.

For more information about the

Armdroid 1, contact: Colne Robotics, 207 Northeast 33rd Street, Fort Lauderdale, FL 33334.

CIRCLE 36

New Products

Preprogrammed Controller

Buckminster Corporation offers the C-1011 Preprogrammed Controller, a fully configured motion system offering turn-key, multi-axis motion control on the STD bus. Buckminster will program the controller to meet exact customer specifications. The C-1011 is useful for many kinds of microprocessor-based motion control, including trajectory control. The controller's capabilities range from single-axis, point-to-point positioning to simultaneous control of as many as 14 closed-loop servo axes.

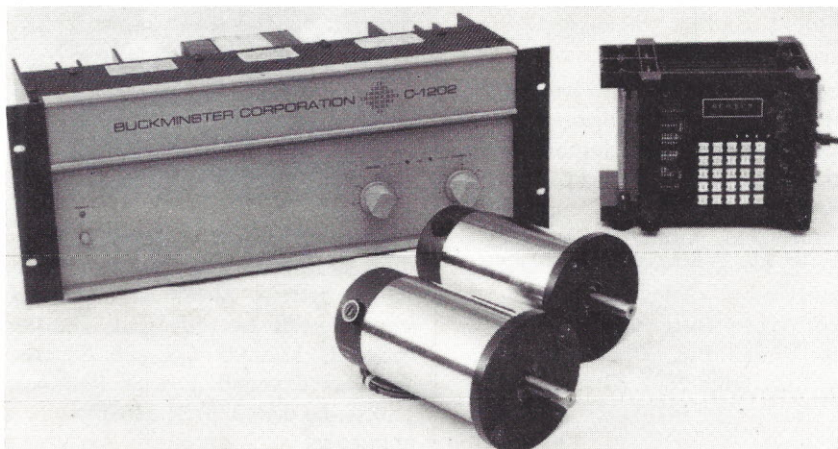
The C-1011 includes DC servomotors and power amplifiers in ap-

propriate sizes and torque ranges. Microprocessor feedback closes all servo loops. Analog tachometers provide velocity feedback. Optical incremental encoders close the feedback loop for point-to-point positioning.

Optional communications protocols allow the C-1011 to be operated from a variety of peripheral devices via an RS-232C connection. Fiber optics, RS-422, and IEEE 488 options are available.

For more information, contact: Jane Palmer, Buckminster Corp., 99 Highland Avenue, Somerville, MA 02143. (617) 864-2456.

CIRCLE 37



Self-Contained Experimental Robot

The RMP 2000 robot motion platform is controlled by an on-board ZX80, ZX81, or Timex/Sinclair 1000 computer. A dedicated microcomputer controls the two drive motor positions, generates audio tones, and simplifies programming from the attached Timex/Sinclair 1000 computer. Batteries power both the RMP 2000 and the computer, so that no wires are attached when the RMP 2000 is in motion.

Control programs are written in BASIC and communicate to the dedicated microcomputer through BASIC POKE and PEEK statements. Docu-

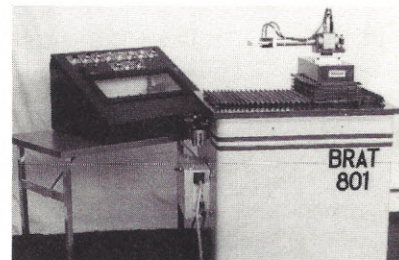


mentation and sample programs are included. The RMP 2000 lists for \$388 without the Timex/Sinclair 1000, which can be added for \$50.

For further information, contact: Bingel Robotics, 3540-224 Southwest Archer Road, Gainesville, FL 32608. (904) 371-6308.

CIRCLE 39

BRAT800



The Basic Robotic Automation Training system is designed to simulate industrial robotic conditions. Its modular construction uses standard industrial components. Optional modules allow students and instructors to re-create various robotic or automated industrial applications in a classroom. The BRAT800 incorporates controllable devices from multiple technologies, including: electronics, pneumatics, mechanics, and computer programming. The attached robot arm moves across the base work surface on an industrial pneumatic manipulator assembly. Various gripper fingers are available for use with the arm.

For more information, contact: Amptronics, Division of TII, Inc., 401 North Salem, Arlington Heights, Illinois 60005. (312) 870-0883.

CIRCLE 38

PC-Logo

Harvard Associates, Inc. has announced the availability of Logo for the PC. PC-Logo is designed to operate in 64K bytes and can use a full 128K bytes. Developed by Gold Hill Computers of Lincoln, Massachusetts, the PC implementation is written in assembly language for rapid execution. PC-Logo features programmable function keys and enhanced editing capabilities. It permits communication through a serial port with such peripheral devices as a mouse and mechanical turtle.

PC-Logo is available from Harvard Associates, Inc., 260 Beacon Street, Somerville, MA 02143. (617) 492-2999.

CIRCLE 40

New Products

6-Axis Force Sensor

The FS6-120A, 6-axis force sensor is an integrated measuring instrument that contains the transducer structure, strain gauges, and instrumentation electronics necessary to completely measure the six components of force, which can be applied to the sensor body by an arbitrary load. The unit contains a built-in microprocessor, which can resolve in real time the 6 force components about any specified coordinate system.

The unit produces an RS-232C-compatible serial bit stream that contains measurements of the instantaneous forces acting on the sensor body. A comprehensive input command language is interpreted by the on-board processor, allowing the

operator to modify the coordinate system and operating parameters using an external terminal or computer. An analog output port is also provided for direct connection to a chart recorder or other analog readout device.

The FS6-120A sensor provides measurements for static and dynamic loads (3 forces, 3 moments). Force measurements range from 0 to 200 Newtons (50 pounds) with a resolution of 0.1 Newton (0.025 pounds). Moment measurements range from 0 to 4 Newton-meters (36 inch-pounds) with a resolution of 0.002 Newton-meters (0.018 inch-pounds). Measurements can be taken at a rate of 500 Hz. The sensor is 120mm in diameter and 55mm high.

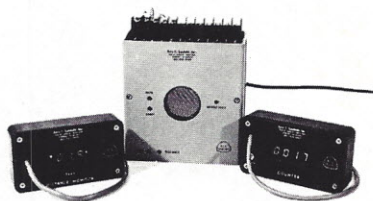


For more information, contact:
Astek Engineering, Inc., 5 Bridge
Street, PO Box 7201, Watertown, MA
02172. (617) 924-2929.

CIRCLE 41

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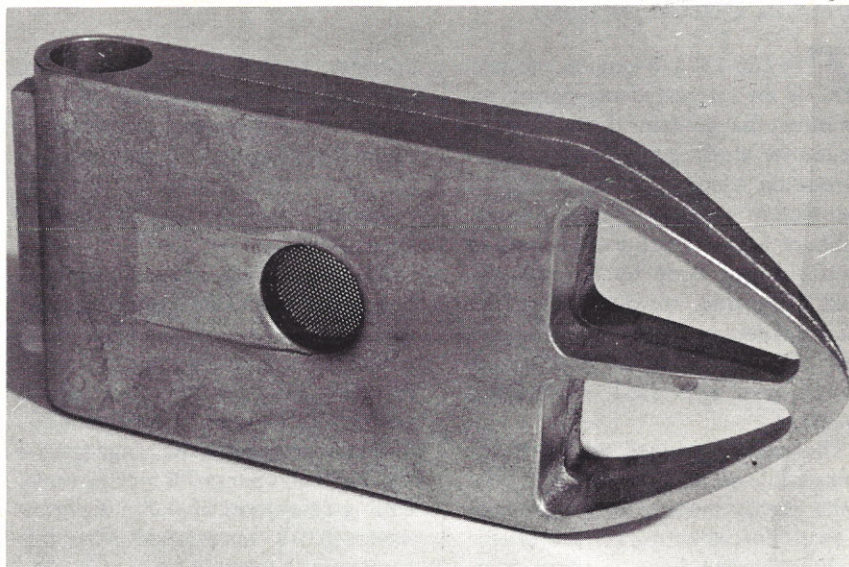
CIRCLE 33

New Products

Distance Control Unit

Originally designed for use in agricultural equipment, the DCU-1 sonic ranging device has two adjustable range settings to detect objects at up to 5 feet. A time gate, set by manual adjustments, defines which of two signal outputs is activated. If an echo returns prior to the gate time (representing a close condition) one output is activated. If the echo does not return by the end of the gate time (representing a far condition) another output is activated. If the echo returns within the specified time gate, representing the correct distance, neither output is activated.

The output can supply up to 8A from the supply voltage for controlling DC motors, solenoid valves, or relays. The DCU-1 has been tested and used under difficult working conditions. A second model, the DCU-



2A, is designed for use in less severe conditions. The DCU-2A has three range settings up to 25 feet.

For further information, contact:

Ezra C. Lundahl, Inc., 710 North 6th West, PO Box 268, Logan, UT 84321. (801) 753-3400.

CIRCLE 42

Classified Advertising

POWERFUL ROBOT MOBILE BASE: RBU-IIT, MAN-RATED, TWIN-DRIVE, TWIN-TREAD UNIT. Specifications: Speed 2 FPS with 100# fully loaded!; Wt. 45 lbs; Dimensions: 24" long, 18" wide, 8" high. This is our rugged 12 VDC 0-50 amp unit suitable for advanced robot projects and rough terrain applications, a result of over 3 years of refinements in design. Only \$625.00! Available from HOBBY ROBOT CO., INC., P.O. Box 887, Hazlehurst, GA 31539. Tel. (912) 375-7821.

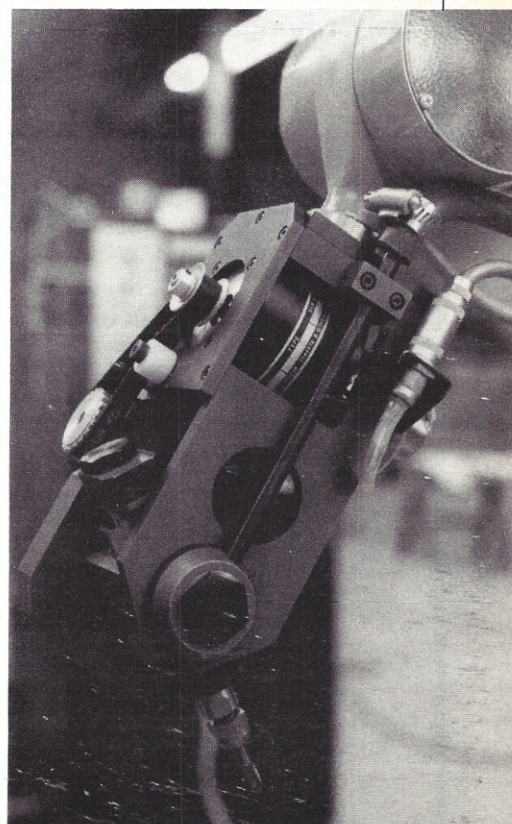
CUSTOM SYSTEMS INTEGRATION—CP/M, MP/M, CP/M-86, UNIX, S-100, IBM-PC, M68000 Add-ons for Heath Robot—Request Catalog. Interface Technology, Box 745, College Park, MD 20740. (301) 490-3608.

6th Axis

E. S-I. produces a servo-controlled drilling/routing/de-burring attachment for ASEA IRB-6 industrial robots. Driven by a 0.33 HP pneumatic motor, the unit provides full 6-axis positioning capability for a cutting tool. The device weighs only 7.3 pounds and is small enough to work inside a 6.50-inch diameter cavity. The 6th axis uses the same position encoder and DC motor as an ASEA robot, for full compatibility with ASEA's controllers. The unit is equipped with collets capable of holding cutting tools with shank diameters from 0.015 to 0.250 inch. This permits use of a wide range of cutting or drilling tools. Spindle rotation is approximately 28,000 RPM under cutting loads. Price is \$6,800 from stock to 10 weeks.

For more information, contact: Robert B. Price, General Manager, E. S-I, Craven Road, Box D, Knox, NY 12107. (518) 895-8954.

CIRCLE 43



INTRODUCING the world's first, affordable teaching robot...

HERO¹ the
most sophisticated
microprocessor-
controlled device
since the
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HERO 1 is a completely self-contained, electro-mechanical robot capable of interacting with its environment. Controlled by an on-board, programmable computer, it has electronic sensors to detect light, sound, motion and obstruction in its path.

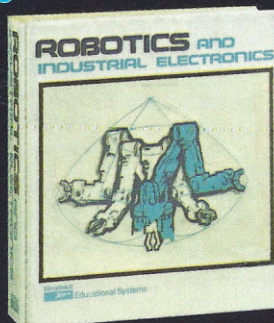
Capable of seven axes of mo-

tion, the robot can be programmed to pick up small objects with its arm. It will also speak in complete sentences, using its voice synthesizer.

Remarkable though the robot is, its companion Robotics Education Course

is an even more significant "first." It provides a thorough understanding of robot technologies, including robotics programming. Course features self-test unit reviews, experiments and final exam.

Designed to be used with HERO 1, this 1200 page course is the most complete introduction to robotics available today.



HERO 1 is a computer on wheels.

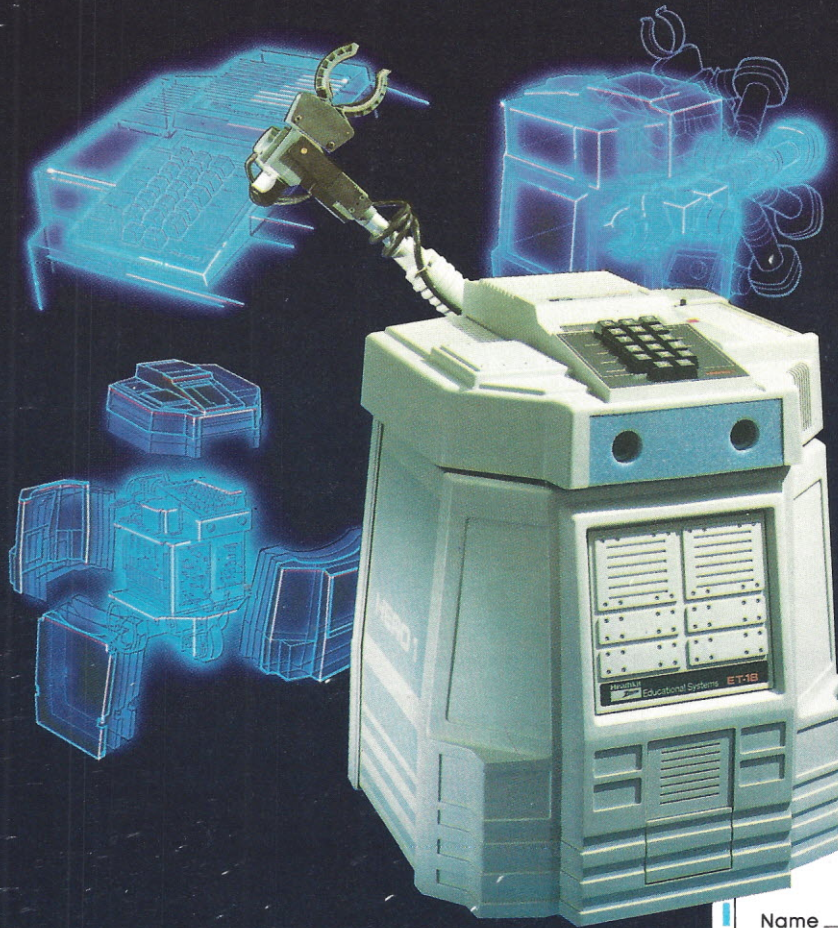
HERO 1 uses a 6808 microprocessor that controls 13 functions and sense boards. Its on-board processor can take it through complex maneuvers. The programming process is straightforward with provision for step-by-step debugging, enhancement and other corrections.

HERO 1 senses include: sound detection (frequency range 200-5000 Hz); light detection; ultrasonic ranging; ultrasonic motion detection; speech synthesis; and real time, four year calendar clock.

A completely mobile platform robot, HERO 1's motion abilities permit head rotation and arm rotation of 350°, shoulder rotation of 150°, arm extension of 5 inches, wrist pivot of 180° and wrist rotation of 350°. Gripper will open to a maximum of 3½ inches and rotate 90° at extreme extension. Payload capacity of arm is 8 oz. at maximum extension and 16 oz. at normal.

The remarkable HERO 1 robot is in production now, ready for you. Buy, assembled or build it from a kit. Kit price is \$1500 and the assembled robot is \$2500, FOB Benton Harbor, or through your nearest Heathkit Electronic Center.

For full information on HERO 1 call 800-253-0570 toll-free. (In Alaska, Hawaii and Michigan, call 616-982-3411.) We'll give you the address of the nearest Heathkit Electronic Center and send you a booklet that gives details about the robot, the content of this course, and other information.



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CIRCLE 10

Heathkit Electronic Centers are units of Veritechnology Electronics Corporation. Heath Company is a subsidiary of Zenith Radio Corporation.

Calendar

Continued from page 2

Robotech 83 will present the latest in applied automation technologies to a qualified audience of users. In addition to company exhibits, a five-track technical program provides a thorough analysis of the automation field.

October 11-12. Computer-Aided Design Conference (CADCON East 83). Park Plaza Hotel and Exposition Center, Boston, MA. Phone: (516) 825-3232.

An engineering conference devoted exclusively to computer-aided design across a wide spectrum of industries, including architecture, aerospace, electronics, automotive, mechanical, marine, electrical, process control, geology, meteorology, and cartology.

October 14-15. 5th Annual Forth Convention. Hyatt Palo Alto, Palo Alto, CA. Contact: Forth Interest Group, Convention Program Chairman, PO Box 1105, San Carlos, CA 94070. (415) 962-8653.

The Forth Convention will feature exhibits and speakers for all levels of Forth enthusiasts, from beginner to professional. Proposed topics to be covered include: hardware Forth machines; Forth-based instrumentation; Forth-based operating systems.

October 18-20. 26th IEEE Machine Tools Conference. Red Carpet Hotel, Milwaukee, WI. Contact: Richard Stobbe, Kearney & Trecker, 11000 Theodore Trecker Way, Milwaukee, WI 53214.

Over 20 papers will be presented on topics including: intelligent vision systems; programmable controllers; sensors; numerical controllers; robotics; drives; servos; motors; flexible machining systems; standards; substrate punching; quality management.

October 18-20. EdCompCon '83. Red Lion Inn, 2050 Gateway Place, San Jose, CA 95110. Contact: M. Dundee Maples, Conference Co-Chairman, Educational Computer, PO Box 535, Cupertino, CA 95015. (408) 252-3224.

The title of this year's EdCompCon is "Applying Technology to Education in the Next Ten Years." The conference will focus on the application of the latest

technology in computer-related areas, hardware, and software, to the area of education.

October 23-26. Symposium on Computer Applications in Medical Care. Baltimore Convention Center, Baltimore, MD. Contact: Ruth E. Dayoff, M.D., SCAMC—Office of CME, 2300 K Street, NW, Washington, DC 20037. (202) 676-4285.

A program designed to inform physicians, health care administrators, biomedical scientists, engineers, and information technology specialists about current and potential applications of computer technology to health care.

October 26-28. 13th International Symposium on Acoustical Imaging. Holiday Inn-Downtown, Minneapolis, MN. Contact: Leslie Denny, Program Coordinator, 220 Nolte Center, University of Minnesota, 315 Pillsbury Drive, SE, Minneapolis, MN 55455.

This symposium is arranged in cooperation with the Institute of Electrical Engineers, Twin Cities Section, and the Office of Naval Research. The scientific program will cover all aspects of acoustical imaging, including its application to medicine, biology, materials testing, underwater investigation, and geophysics.

Sensory Perceptions

Continued from page 11

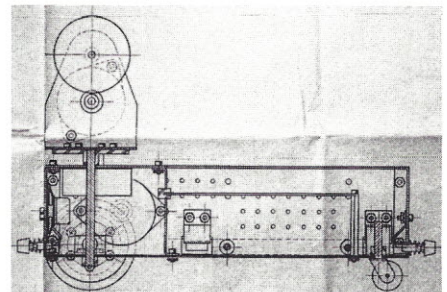
ment of computer-aided manufacturing technology, has announced a Robotics Software project. The project has three proposed objectives. The first is a specification for a robot-independent language. Once the specification is completed, a prototype robotic software system incorporating a graphic simulator will be constructed. The basic system will then be expanded to use graphic data as the basis for automatic robot programming. Project participation is available to all organizations within regions approved by the US Department of Commerce. For more information, contact: CAM-I, 611 Ryan Plaza Drive, Suite 1107, Arlington, TX 76011. (817) 265-5328.

PERSONAL ROBOTICS NEWS. This monthly newsletter will cover developments in hardware and software, market

trends, applications, and government legislation. Subscriptions are priced at \$125. For further information, contact: PRN Publishing Company, PO Box 10058, Berkeley, CA 94709. (415) 524-7115.

FORTH. The Forth language seems to be fast becoming the language for single-board controllers. The development of single-chip Forth machines would hasten this trend. Rockwell International has introduced its R65F11 and R65F12 Forth-based microcomputers. The microcomputers feature an enhanced 6502 processor with four new instructions: set memory bit, reset memory bit, branch on bit set, and branch on bit reset. The enhanced processor also has decimal and binary arithmetic modes, 13 addressing modes, and true indexing. At least one company (New Micros, Inc. of

Grand Prairie, Texas) has already designed a single-board controller using the Rockwell chip.



SCORPIONS. It seems that whenever I turn around, a new robotic creature appears. Rhino Robots is breaking away from their image as a robot arm manufacturer to create a small, mobile robot called the Scorpion. The accompanying photograph was taken from preliminary plans for the new robot. We'll announce new information as it is available.

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